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Thermal sum accumulated in development stages of tomato crop for industrial processing

Fábio Miguel Knapp, José Alves Júnior*, Rafael Battisti, Ricardo Souza Bezerra, Adão Wagner Pêgo Evangelista, Derblai Casaroli, Fillipe de Paula Almeida

School of Agronomy, Department of Soil and Water, Federal University of Goiás (UFG), Zip code 74.690.900, Goiania, Goiás, Brazil

***Corresponding author: josealvesufg@ufg.br**

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Abstract: Tomato crop for industrial processing is very sensitive to weather variations. Therefore, the objective of this research was to quantify the duration (days and thermal sum) of each developmental stage of different hybrids in two different planting date. For this, 12 commercial hybrids were evaluated: H-1301, BS-P0033, CVR-8161, HM-7885, CVR-6116, HM-7883, H-1536, CVR-2909, TPX-26856, CVR-8126, CTI-35 and N-901, in Abadia de Goiás, Brazil, planted on 03/31/2020 and 05/26/2020. Experimental area with 3,120 m^2, 4 blocks with 12 experimental plots each (12 hybrids), and each plot, formed by 3 double planting lines of 10 m, spaced 0.6 m x 1.2 m, with plants every 0.37 m, totaling 27 plants per line and 162 plants per plot. Plant phenology was monitored daily: phase I (planting to set), phase II (set to flowering), phase III (flowering to beginning of maturation) and phase IV (IVa beginning of maturation up to 50% of mature fruits and phase IVb (from 50% to 90% of mature fruits). The results show, on average of all hybrids, thermal sum of 1,394 and 1,364 ^{o}C obtained in 124.6 and 116.1 days of cycle, in first and second cycle, respectively. In first cycle, there was a difference in thermal sum between the hybrids in stage IV and in total cycle, which hybrids BS-P0033, CVR-8161, HM-7885, HM-7883, CVR-2909 and TPX-26856 accumulated from 81.29 to 112.88 ^{o}C in 6 to 9.3 days to complete maturation, while other hybrids accumulated from 122.85 to 148.11 ^{o}C in 10.3 to 13 days. The hybrids BS-P0033, CVR-8161, HM-7885 and HM-7883 had a shorter total cycle duration from 1,334.21 to 1,379.98 ^{o}C (119 to 123 days), while other hybrids variated of 1,391.45 to 1,437.05 ^{o}C (124.3 to 129 days). The stages of setting, vegetative and beginning of maturation up to 50% of ripe fruits, showed variation in thermal sum and duration of phase, depending on planting date. For the first cycle, the duration of average vegetative stage was 21.7% longer, accumulating 34.1% more ^{o}C, compared to the second cycle, providing greater plant height (43.8%) and higher productivity (19.8%). This shows that is need to change irrigation management strategy between transplanting date and crop development stages, making irrigation adjustments by thermal sum and not by number of days for development stage.

Keywords: *Solanum lycopersicum*; tomato cultivation; degrees day; temperature; brazilian savanna.

Introduction

The tomato (*Solanum lycopersicum*) is one of the most cultivated vegetables in the world. It is present daily in the diet of the world population and has great socioeconomic importance (Schwarz et al., 2013). In Brazil, tomato cultivation for industrial processing is concentrated in the Center-West and Southeast regions of the country. The state of Goiás is the largest producer, with an estimated area of 10 thousand hectares (IBGE, 2019).

To optimize tomato cultivation it is necessary to take into account genetic factors (hybrids), planting times and management (fertilization and irrigation), which affect the productivity (Silva et al., 2020). When choosing genetic material, the main factors to consider are the length of the cycle, the concentration of soluble solids, the color and acidity of the fruit, as well as resistance to diseases and pests (Silva et al., 2006). Tomato production is also strongly dependent of environment, and crop cycle can vary in days, depending of genotypic characteristics and local weather conditions (Rocco and Morabito, 2016), mainly due to variations of air temperature. Air temperature influences tomato plants growth and development, altering crop phenology (Pathak and Stoddard, 2018), affecting growth rate, crop cycle length and productivity (Floss, 2011).

In the state of Goiás (center of Brazil), tomatoes for industrial processing are planted from February (end summer) to June (beginning winter) and harvested from July (winter) to October (spring). Early plantings in February and March are restricted by high air humidity, which causes phytosanitary problems. Late plantings, in June and July, receive rain during harvest period, which reduces the quality of the fruit and increases the difficulty of mechanized harvesting (Giordano and Silva, 2000).

Planting from February to March results in a cycle that is approximately 15 days longer than planting from June to

July. This is due to lower temperatures during June and July, prolonging the crop cycle (Silva et al., 2006). Therefore, in second plantings, producers should opt for hybrids with greater thermal accumulation requirements, in order to relatively prolong the cycle, increasing plant height and leaf area index, minimizing productivity losses. Due to these interactions between environment, planting date and hybrid, different management strategies should be used to maximize the use of resources.

As rainfall decreases from March onwards in Goiás, tomato crop receives irrigation, mainly by central pivot, in all or part crop cycle. For irrigation management, reference evapotranspiration (ETo) and crop coefficient (Kc) suggested by FAO 56 and Embrapa were used (Allen, et al., 1998; Silva et al., 2006). Kc values vary according to crop's development stage, however, operationally there is a difficulty in determining the exact change in the stage of development, which varies between planting seasons and hybrids, mainly due to air temperature, and consequently causes errors in use of Kc which commonly follows a prefixed duration in days (Pathak and Stoddard, 2018), leading to errors in crop irrigation management (Alves Jr. et al., 2021).

Thus, given the scarcity of information about it, the aim this study was to determine the thermal sum and duration of each development stage of 12 tomato hybrids for industrial processing, grown in two planting seasons, and identify the main variation causes.

Results and Discussion

Weather data

For the first planting, the average air temperature was 21.07 °C during crop cycle, varying from 8.60 to 32.50 °C (Figure 1A). The accumulated global solar irradiance was 2,292 MJ m^{-2} $cycle^{-1}$ (Figure 1A), accumulated rainfall was 211.8 mm $cycle^{-1}$, occurring in the first week after planting, irrigation total was 209.6 mm $cycle^{-1}$, and the average ETo was 2.94 mm day^{-1} . For the second planting the average air temperature was 21.84 °C, varying from 8.06 to 35.70 °C, accumulated global solar irradiance of 2283 MJ m^{-2} (Figure 1B), accumulated rainfall of 0 mm and irrigation of 258.2 mm, and average ETo of 3.55 mm day ^{1}.

Thermal sum

For the first planting, in phase I (planting to set), there was no statistical difference between 12 hybrids, with an average accumulated of thermal sum of 108.1 °C, varying from 91 to 120.2 °C, in an average of 7.2 days, varying from 6 to 8 days (Table 2), confirming Marouelli and Silva (2002), who found an average of 7 days to phase I, varying from 6 to 9 days. To stage II (set to flowering), there was no difference between 12 hybrids, with an average accumulated of thermal sum (12 hybrids) of 381.4 °C, varying from 347 to 450.9 °C, in an average of 32 days, varying from 29 to 38 days (Table 2). The duration of phase II was from 6 to 11 days longer than reported by Marouelli and Silva (2002), who obtained from 23 to 27 days in phase II, but for different hybrids.

For reproductive stage, phase III (flowering to beginning of maturation), 12 hybrids had an average accumulated of thermal sum of 530.7 °C, varying from 438.7 to 576 °C, in an average of 49.8 days, varying from 41 to 54 days (Table 1). Marouelli and Silva (2002) found from 50 to 60 days in phase III. To phase Iva (beginning of maturation up to 50% of mature fruits) average accumulated of thermal sum was 259.6 °C, varying from 205.8 to 330.6 °C, in an average of 26.2 days, from 21 to 33 days (Table 1).

The hybrids BS-P33, CVR-8161, HM-7885 and HM-7883 had lowest thermal accumulated thermal sum, statistically different from other hybrids, which varied from 1,365.14 to 1,379.98 °C (total cycle), in 121.5 to 123 days. However, the highest average accumulated of thermal sum were hybrids H-1301, CVR-6116, H1536, CVR-2909, TPX-26856, CVR-8126, CT-35 and N-90, with 1,391.4 to 1,437.0 °C (total cycle), in 124.3 to 129 days. The lowest yields were obtained with hybrids CTI-35 and H-1536, intermediate yields with hybrids H-1301, CRV-6116 and N-901, and the highest yields with hybrids: HM-7885, CVR-2909, CVR-8126, TPX-26856, HM7883, BS-P33. The hybrids with highest yields also had lowest accumulated thermal sum, except to TPX-26856 and CRV-8126.

For the second plantings, there was no significant difference in duration of development stages to 12 hybrids. To phase I, average accumulated of thermal sum was 73.9 °C in 7.7 days (Table 2). To phase II, average accumulated of thermal sum was of 284.4 °C in 26.3 days. To phase III, average accumulated of thermal sum was of 552.3 °C in 50.5 days. To phase IVa was of 322 °C in 23.4 days, and phase IVb (from 50% to 90% of mature fruits) was of 130.5 °C in 8.2 days, totalizing 1364.7 °C (varying from 1311.5 to 1398.7 °C) in 116.1 days (varying from 113 to 118 days) (Table 2). These results are in line with those reported by Marouelli and Silva (2002), who found similar results to different hybrids.

To second planting, average yield was 123.73 t ha^{-1} (Table 3.2), above national average yield of 71.9 t ha^{-1} (FAO, 2017). The hybrid with highest yield in second planting was CVR-8161 with 140.56 t ha^{-1}, which did not differ of hybrids BS-P33, HM-7885, HM-7883, TPX-26856, CVR-2909 and CVR-8126. The hybrid with lowest yield was CTI-35 with 106.91 t ha^{-1} (Table 2).

When analyzing the seasons (first and second planting), there was a significant difference in duration of phases I, II and IVa and total crop cycle (Appendix 4). To phase I, average accumulated of thermal sum was of 108.1 and 73.9 °C (12 hybrids) to first and second planting, respectively (Table 3). The average of air temperature was 7 °C higher in first than in second planting, 25.15 °C and 18 °C, respectively (Figure 1), 3 °C higher than ideal air temperature, affecting young plants development (Ayenan et al., 2019). To phase I, higher air temperature and consequently a higher daily thermal accumulation, associated with the initial stress due to transplanting, resulted in an delay for young plants sprout new leaves, as reported by Andriolo et al. (2003). The environmental stress caused by change in air temperature and solar radiation affects the initial stage (phase I) until it acclimatizes and prolongs crop setting stage.

To phase II, average accumulated of thermal sum was 381.4 °C in 32 days (First planting), and 284.4 °C in 26.3 days (Second planting). So there was a significant difference between two seasons (Table 3). This represents an increase of 34.1 and 21.7% in thermal sum and cycle days, respectively. This increase is consequence of rainfall occurred in first planting in beginning of phase II, and a reduction in solar radiation on some days, associated with a lower average air temperature (Figure 1, Table 3), causing increase crop cycle, as reported by Lopes and Lima (2015). There was a greater vegetative growth of plants with a 44.1% increase in plant height, a 13.5% increase in the number of branches, an increase in the dry mass of stems and branches of 73.4 and 46.9%, respectively, and a 19.8% increase in productivity (Table 4), as reported by Ilic et al. (2014) and Yang et al. (2019), who obtained higher tomato yields with an increase in plant height and number of branches.

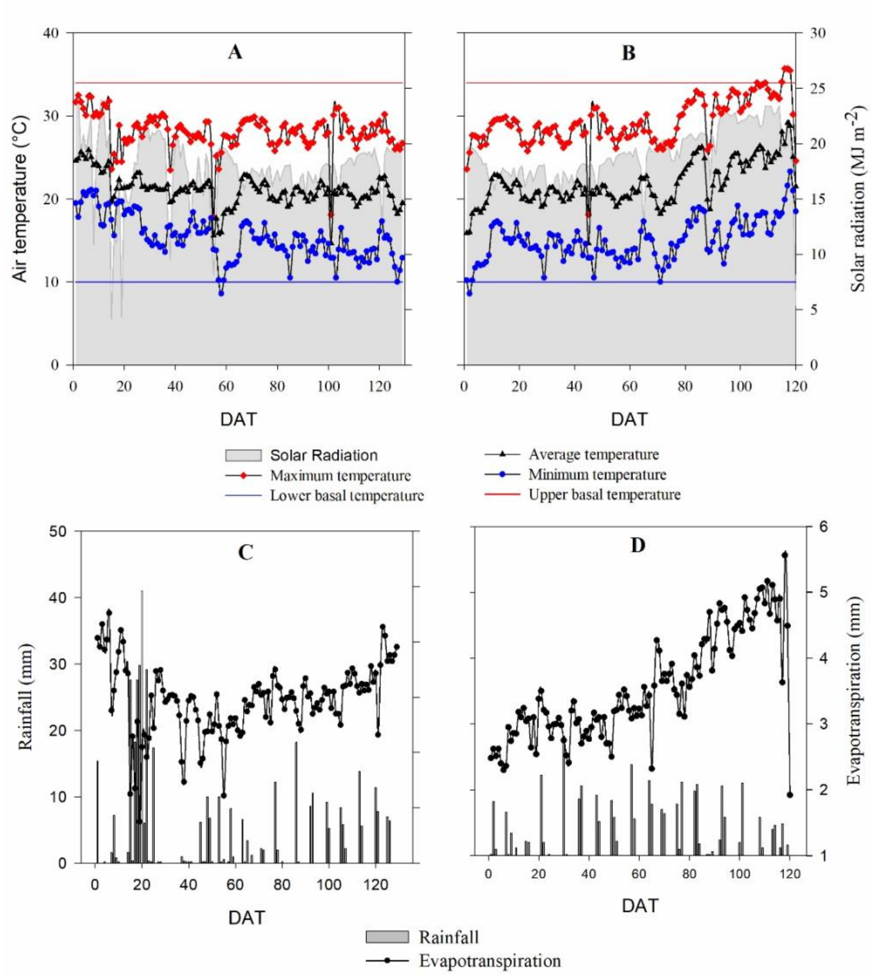

Figure 1. Daily solar irradiance (Rad), maximum air temperature (Tmax), average air temperature (Tmed) and minimum air temperature (Tmin), lower basal temperature (Tb), upper basal temperature (TB), precipitation/irrigation and daily evapotranspiration for the first growing season from March 31 to August 6, 2020 (A, C) and the second season from May 26 to September 22, 2020 (B, D), Abadia of Goiás - GO, Brazil.

Table 1. Duration in days of development stages (I: planting to setting; II: setting to flowering; III: flowering to beginning of maturation; IV: maturation to harvest) of 12 industrial tomato hybrids, and accumulated thermal sum (GDA), in Abadia of Goiás-GO, Brazil (planting on 31/03/2020, 1st planting).

Hybrid	Phase I		Phase II		Phase III		Phase IVa		Phase IVb		Total cycle		Yield (t ha^{-1})
	ST	Days	ST	Days	ST	Days	ST	Days	ST	Days	ST	Days	
H-1301	106	7	380	32	496	47	135	29	123 b	10 b	1391 b	124 b	135 b
BS-P33	113	8	404	34	531	50	147	24	81 a	6, a	1365 a	122 a	147 a
CVR-8161	106	7	367	30	534	50	160	27	106 a	9 a	1380 a	123 a	160 a
HM-7885	113	8	360	30	546	51	190	26	86 a	7 a	1365 a	122 a	190 a
CVR-6116	106	7	372	31	528	50	140	27	137 b	12 b	1410 b	126 b	140 b
HM-7883	98	7	369	31	509	48	150	27	88 a	7 a	1334 a	119 a	150 a
H-1536	105	7	406	34	528	50	116	25	147 b	13 b	1430 b	128 b	116 c
CVR-2909	105	7	388	33	534	50	173	27	113 a	9 a	1405 b	126 b	173 a
TPX-26856	113	8	386	33	523	49	157	2	104 a	8 a	1393 b	125 b	157 a
CVR-8126	106	7	385	32	530	50	163	27	130 b	11 b	1419 b	127 b	163 a
CTI-35	106	7	381	32	561	53	109	25	148 b	13 b	1437 b	129 b	109 c
N-901	120	8	378	32	549	52	139	25	119 b	10 b	1408 b	126 b	139 b
Average	108	7,2	381	32	531	50	260	26	115	9	1394,9	124,6	148
Maximum	120	8,0	451	38	576	54	330	33	199	18	1446,8	130,0	228
Minimum	91	6,0	348	29	439	41	206	21	58	4	1321,9	118,0	87
Des. Pad.	14.4	1.0	23.6	2.2	34.4	3.3	30.8	2.9	36.9	3.7	37.6	3.8	27.18
CV (%)	13.3	13.8	6.2	6.7	6.5	6.6	11.8	11.2	32.0	39.3	2.7	3.0	12.99

ST = thermal accumulation of phase; Days = Days of phase; Phase 1 = Planting to setting (when a new leaf has emerged and reached 4 cm in length); Phase 2 = Setting until the beginning of reproductive period (more than 50% of plants with a flower at anthesis) Phase 3 = Reproductive to beginning of maturation (first fruit with color change); Phase 4a = Beginning of maturation to 50% of mature fruit; Phase 4b = From 50% of mature fruit to 90% of mature fruit.

Table 2. Duration, in days, of the development stages (I: planting to setting; II: setting to flowering; III: flowering to beginning of maturation; IV: maturation to harvest) and productivity of 12 tomato hybrids for industry, in days accumulated thermal sum (GDA), in Abadia de Goiás-GO (planting day 26/05/2020, 2nd planting).

Hybrid	Phase I		Phase II		Phase III		Phase IVa		Phase IVb		Total cycle		Yield.
	ST	Days	ST	Days	ST	Days	ST	Days	ST	Days	ST	Days	(t ha^{-1})
H-1301	71	8	275	25	543	50	347	25	107	7	1343	115	117 b
BS-P33	66	7	293	27	561	51	300	22	115	8	1335	114	127 a
CVR-8161	77	8	284	26	551	50	353	26	119	7	1385	117	141 a
HM-7885	84	9	263	25	539	50	292	22	146	10	1335	115	137 a
CVR-6116	76	8	286	26	55	51	316	23	135	9	1371	117	115 b
HM-7883	77	8	292	27	528	49	338	25	127	8	1363	116	136 a
H-1536	7	8	299	28	537	49	339	25	120	8	1371	117	108 b
CVR-2909	66	7	293	27	546	50	331	24	149	9	1385	117	125 a
TPX-26856	66	7	280	26	574	52	300	22	151	10	1371	117	129 a
CVR-8126	84	9	270	25	536	50	361	26	134	8	1385	117	131 a
CTI-35	66	7	304	28	573	52	308	22	134	8	1385	117	107 b
N-901	79	8	275	26	582	53	285	21	129	8	1349	115	112 b
Average	74	8	284	26,3	552	51	323	23	131	8	1365	11	124
Maximum	101	10	314	29,0	613	55	421	30	210	13	1399	118	154
Minimum	56	6	219	21,0	441	42	238	18	60	4	1312	113	76
Des. Pad,	15.1	1.4	23.5	2.1	44.2	3.3	45.2	3.0	32.5	1.9	31.1	1.7	18.59
CV (%)	23.2	19.6	8.0	7.9	8.5	6.8	14.1	13.0	26.0	24.8	2.0	1.3	12.45

Days = Days of phase;;Stage 1 = Planting to setting (when a new leaf has emerged and reached 4 cm in length); Stage 2 = Setting until beginning of reproductive period (more than 50% of plants with a flower at anthesis); Stage 3 = Reproductive to beginning of maturation (first fruit with color change); Stage 4a = Beginning of maturation to 50% of mature fruit; Stage 4b = From 50% of mature fruit to 90% of mature fruit.

Table 3. Average duration of development stages (phase I: planting to setting; phase II: setting to flowering; phase III: flowering to beginning of maturation; phase IVa: beginning of maturation to 50% of mature fruit; phase IVb: maturation from 50% of fruit to harvest) of 12 industrial tomato hybrids, in days accumulated thermal sum (GDA) in two planting seasons, in Abadia de Goiás-GO, Brazil.

Seasons	Phase I		Phase II		PhaseIII	
	ST	Days	ST	Days	ST	Days
1	108 a	7	381 a	32 a	531	50
2	74 b	8	284 b	26 b	552	51
Seasons	**Phase IVa**		**Phase IVb**		**Total cycle**	
	ST	Days	ST	Days	ST	Days
1	260 b	26	115	10	1395	125 a
2	323a	23	131	8	1365	116 b

ST = thermal accumulation of phase

To phase IVa, second planting had a greater average accumulated of thermal sum of 322.6 °C (23.6 days), 24.3% more than 259.6 °C (26.2 days) in first planting. First planting was 2.6 days higher than second planting, even though it accumulated less thermal energy, as reported by Marouelli & Silva (2002) (Table 4).

In maturation stage (phase IVa), there was an increase of 3 °C in average air temperature between first (20.4 °C) and second (23.4 °C) planting, with maximum air temperature 34 °C, and an increase in solar radiation of 3.8 MJ m^{-2} day^{-1} (Figure 1). Similar results, increase in temperature of 14.7% and solar radiation of 20.7% in phase IVa (Figure 1), was also report by Casaroli et al. (2018) and Leite et al. (2020). As a consequence of the increase air temperature there was also increase of accumulated th)ermal sum in 24.3% and shortened crop cycle in 10.8% (in second planting). The high temperature with greater incidence of solar radiation (Figure 1) in maturation phase accelerated leaf senescence and reduced leaf retention (Table 1), as also report by Goto et al. (2021). Excess of solar radiation in fruit maturation stage cause greater leaf senescence. The greater leaf senescence in second planting, fruit scalding occurred, reducing quality and productivity in 16.6% (Table 1). Similar results was reported by Silva et al. (2006), Ayenan et al. (2019) and Goto et al. (2021), high air temperature and incidence of solar radiation in phase IVa limited tomato productivity.

To phase III (longer phase) there was no difference in duration between planting seasons (Table 3). This was probably due to average air temperature found of 20.5 and 21 °C for first and second seasons respectively (Figure 1). According to Ayenan et al. (2019), optimal average air temperatures for tomato crop is between 18.5 and 21 °C for reproductive stage.

The total thermal accumulation for the first planting was 1,394.9 °C in 124.6 days, and for second planting 1,364.7 °C in 116.1 days of cycle, as report by Alves Jr. et al. (2021) to CVR-2909, N-901 HM-7885 H-1301 hybrids. According to Pathak and Stoddard (2018), tomatoes for industrial processing had a total cycle length of 1214 °C, in a varying from 117 to 135 days, depending of planting season and consequently of weather conditions. The same authors report of a shortening of tomato phases in days with increasing temperatures, without affecting thermal sum required to complete the cycle, affecting fruits quality and total productivity.

Table 4. Average duration of number of branches, plant height, number of fruits, dry mass of stem (DRStem), dry mass of branches (DRBranches), dry mass of leaves (DRleaf), and productivity, in two planting seasons, in Abadia de Goiás-GO, Brazil.

Seasons	Branches (und.)	Stem (cm.)	Fruits (und.)	DRStem (g)	DRBranches (g)	DRleaf (g)	Yield (t ha^{-1})
1	10.52 a	114.02 a	157.58 a	12.73 a	82.31 a	78.07 a	148.25 a
2	9.27 b	79.08 b	113.44 b	7.34 b	56.04 b	61.47 b	123.73 b

Averages followed by same letter in column do not differ by the Tukey's test at a 5% probability of error.

Materials and Methods

Location, climate and soil

The study was carried out at Cargill's experimental station in Abadia of Goiás - GO (16.8° S and 49.4° W, and elevation 887 m). The climate is tropical (Aw), characterized by dry winter and rainy summer with average annual of air temperature of 23.1 °C and average annual rainfall of 1,414 mm, as classified by Köppen (Alvares et al., 2013).

The soil classification was Latossolo Vermelho Distrófico (EMBRAPA, 2006). Soil chemical analysis in 0.0 - 0.4 m layer showed before planting: pH ($CaCl_2$) = 5.9; MO = 24.0 g dm^{-3}; P (Mehlich) = 3.05 mg dm^{-3}; Al = 0.0 mmolc dm^{-3}; H+Al = 2.55 cmolc dm^{-3}; K = 88.1 mg dm^{-3}; Ca = 2.7 cmolc dm^{-3}; Mg = 0.7 cmolc dm^{-3}; CTC = 5.52 cmolc dm^{-3}; V(%) = 53.66%; and soil physical characteristics: Sand = 55%; Silt = 9.5% and Clay= 35.5% (sandy loam texture); with water retention estimated at 1.5 mm cm^{-1}.

Experimental setup

To correct soil fertility, 5 t ha^{-1} of dolomitic limestone was distributed by hand to raise base saturation to 70%, followed by sub-soiling to 0.5 m depth. The soil was then harrowed twice. Three months later, the soil was harrowed twice, once for plowing and once for leveling. For planting, the area was furrowed to 0.15 m depth, in double rows spaced 0.60 x 1.20 m, with plants every 0.37 m. The seedlings were transplanted on 31/03/2020 for 1st planting and on 26/05/2020 for 2nd planting. The seedlings were 45 days old in nursery of 12 tomato hybrids for industrial processing: H-1301, BS-P0033, CVR-8161, HM-7885, CVR-6116, HM-7883, H-1536, CVR-2909, TPX-26856, CVR-8126, CTI-35 and N-901.

For basic fertilization at planting, 273 kg ha^{-1} of potassium chloride was applied, 1,000 kg ha^{-1} of granulated MAP and 58 kg of zinc sulphate in planting furrow. Top dressing was applied by fertigation with 31 kg ha^{-1} of MAP, 353 kg ha^{-1} of ammonium nitrate, 419 kg of potassium chloride, 242 kg of ammonium sulphate, 210 kg ha^{-1} of magnesium sulphate and 22 kg ha^{-1} of boric acid. In addition to fertilization, weed control and plant health management were carried out as recommended by Cargill's agricultural department.

The trial was set up in a two-season randomized block design, with 12 hybrids and four replications, totaling 96 experimental plots. Each plot consisted of 3 double planting lines of 10 m, spaced 0.6 m x 1.2 m, with plants every 0.37 m, totaling 27 plants per line and 162 plants per plot. A total of 150 plants were considered useful per plot, with the first and last plants in each row considered a border. A 2 m strip between blocks was used as a border to move around the area and install the irrigation system.

The conventional sprinkler irrigation system was installed in the area with impact sprinklers (Implebrás / IM35 / 4.0 x 2.5 mm / 35 mca / 1.7 $m3\ h^{-1}$ / 11.8 mm h^{-1}, 80% efficiency) spaced 12 x 12 m, between sprinklers on the lateral irrigation line and between lateral lines, respectively.

For irrigation, 15 mm was applied before (the day before) and 5 mm on the day^{-1} immediately after transplanting until setting. During the first 5 days of cycle, irrigation was carried out daily and, thereafter, when the soil water depletion was close to 40% of storage. To calculate soil water storage, 1.5 mm cm^{-1}, and effective root depths of 0.1, 0.2 and 0.3 m were considered for phases I, II and III/IV, respectively.

Irrigation was managed by replacing crop's evapotranspiration, obtained by the product of reference evapotranspirations (ETo) obtained by Penman-Monteith (Allen et al., 1998). Estimated using data from Metos automatic weather station which monitored solar radiation, wind speed, temperature and relative humidity, installed 50 m from experimental area. The crop coefficients (Kc) used were those recommended by Marouelli and Silva (2002) and Marouelli et al. (2012), with Kc of 0.9 in phase I (planting to setting), Kc of 0.65 to 1.1 in phase II (setting to flowering), Kc of 1.1 in phase III (flowering to maturation), Kc of 1.1 to 0.35 in phase IVa (beginning maturation of first fruit until 50% fruit mature), and Kc of 0.35 in phase IVb (50% fruit mature until harvest).

Plants measurements and thermal sum calculation

To monitor phenology, 10 plants were randomly selected and identified in each experimental plot and evaluated daily. The phases included: phase I (planting to setting) - setting was considered when a new leaf was issued and reached 4 cm in length; phase II (setting to flowering) - flowering was considered when more than 50% of the plants had flowers at anthesis; phase III (flowering to maturation) - the beginning maturation was considered when was observed change color of the first fruit; phase IV was divided into phase IVa (beginning maturation of first fruit until 50% fruit mature) and phase IVb (50% fruit mature to 90% of fruit mature / harvest).

The daily thermal sum was determined considering daily air temperature data from weather station, and the lower basal temperature (Tb) of 10 °C and the upper basal temperature (TB) of 34 °C, by reported by Pivetta et al. (2007) and Palaretti et al. (2012), and the Degree Days (GDi /) were obtained using the following equations (Ometto, 1981):

For days when TB > TMax > Tmin > Tb:

$$GD_i\ (°C) = \frac{(TMax+Tmin)}{2-Tb}$$

When TB > TMax > Tb > Tmin:

$$GD_i\ (°C)=\frac{(TMax - Tb)^2}{2(TMax-Tmin)}$$

When Tb > TMax:

$$GD_i = 0$$

When TMax > TB > Tmin > Tb:

$$GD_i\ (°C)=\frac{2.(TMax- Tmin) . (Tmin - Tb)+(TMax - Tmin)^2 - (TMax - TB)}{2.(TMax - Tmin)}$$

When TMax > TB > Tb > Tmin:

$$GD_i(°C) = \frac{1}{2} . \frac{(TMax -Tb)^2 - (TMax - TB)^2}{(TMax -Tmin)}$$

where: GDi is the sum of degree days of the day in °C, TMax and Tmin represent the maximum and minimum temperature of the day, respectively, in °C, Tb and TB represent lower and upper basal temperatures, respectively, in °C.

In end of crop cycle, fruit was harvested for yield analysis, counting: number of fruits per plant, branches per plant and plant height (main stem). The fruit, branches, main stem and remaining leaves were packed in paper bags and dried in oven at 60°C until constant mass to determine yield and dry plant biomass.

Statistical analysis

The data obtained was subjected to analysis of variance using the F test individually and jointly, at 5% probability of error level using the GENES program, and when significant, means were compared by Scott and Knott test, at a 5% probability of error level (Cruz, 2013).

Conclusion

To first planting (March) there was difference in average thermal sum and cycle length in days between 12 hybrids evaluated, being the shortest cycle BS-P33, CVR-8161, HM-7885 and HM-7883 varying from 1365.14 to 1379.98 °C in 121.5 to 123 days, while the longest cycle H1301, CVR-6116, H1536, CVR-2909, TPX-26856, CVR-8126, CT-35 and N-901 varying from 1391.45 to 1437.05 °C in 124.3 to 129 days.

To second planting (May) there was no difference between 12 hybrids, with an average of 1364.7 °C in 123.73 days of cycle.

The main phases influenced by transplanting time (planting season) were phases II and IV (vegetative phase and mature fruit, respectively), influenced mainly by average air temperature. This shows that there is a need to change irrigation management strategy to each planting season, making irrigation adjustments taking into account the accumulated thermal sum and not the number of days pre-set for each development stage.

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