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Genetic variation in agronomic traits and yield performances of tomato (*Solanum lycopersicum*) genotypes in response to heat stress

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Abstract

High temperature is one of the most unfavourable factors which affects biochemical, morphological, and physiological facets of tomato, decreases normal growth and subsequently reduces the crop yield. The optimal daily mean temperature for tomato fruit set under field conditions is between 21 and 24°C. While Cambodia has high temperature in a couple of months (e.g. March-May) up to 38°C, resulting in low productivity or even no production of tomato available during this period. The aim of this study was to investigate the performance of various tomato genotypes under high temperature between February-May 2019. Eight tomato lines (CLN3736D, CLN3078G, CLN3212C, CLN3024A, CLN2498D, CLN3125L, CLN1621, CLN2026D) and two local varieties as check varieties (KK1 and Neang Tamm) were selected for the study. The highest temperature during the trial was up to 38°C with an average day temperature of around 30°C. This experiment was conducted in the open field of crop station (sandy loam) at the Royal University of Agriculture and was laid out in a Randomized Complete Block Design (RCBD) with three replications. The results showed that (KK1) had the highest total fruit yield (785.72 g plant^{-1}) followed by CLN1621L (585.77 g plant^{-1}) and CLN3212 (449.84g plant^{-1}). Moreover, CLN1621L produced the highest number of fruits per plant (23 fruits plant^{-1}) followed by KK1 and CLN3212C3 with 10.84 fruit plant^{-1}. Based on this study, KK1, CLN1621L and CLN3212C performed the best during this high temperature span. Further study on agronomic practices such as crop rotation, pest controls, grafting, etc. should be investigated to enhance the productivity of these potential genotypes. Fruit size preference should also be considered to select potential genotypes for commercial purposes.

Keywords: Tomato genotypes, agronomic performance, heat tolerance.

Introduction

Tomato (*Solanum lycopersicum*) is one of the most popular vegetables which contains vitamins and minerals necessary for human dietary intake (Dorais et al 2008). There are roughly 4,762,457 hectares of cultivated tomato with 182.3 million metric tons worldwide (FAOSTAT, 2018). In a temperate climate, favorable conditions can be found for the cultivation of tomatoes. It causes drastic reductions in tomato flowering and fruit set and in fruit size and also quality (Harel et al. 2014). Singh et al. 2015 reported that the temperature at 38°C for 3 to 4 hours is most sensitive to the flowering period of the tomato. It has effect on pollination, lower number of seeds or grains and limiting crop yield, because of failure in reproductive processes such as pollen tube growth, fertilization, and early embryo development (Kartikeya et al. 2012). Moreover, heat stress reduced or abnormal pollen production, abnormal development of the female reproductive tissues, hormonal imbalances, low levels of carbohydrates, and lack of pollination (Pushparani et al. 2017).

At high temperatures (an increase of 3°C to 5°C above normal), most tomato cultivars have problems with fruit set, pollen meiosis and germination, ovule development and viability, and development of the embryo (Jiang 2016). Seed germination, seedling and vegetative growth, flowering, fruit set, and fruit ripening are adversely affected at a temperature of above 35°C (Thomas et al. 2004; Prasad et al. 2008; Wahid et al. 2007). Heat resistant characteristics that may be imperative steps of crop growth such as germination of seed, reproductive and vegetative steps. Heat tolerance is a critical character of tomato varieties targeted for production in the tropics and sub-tropics as Cambodia. The country has a tropical climate with warm temperatures throughout the year. There are two seasons: dry season runs from December to April and cool season

is from May to November (Cambodia Weather-Climate, 2020). Nowadays, tomato is a popular crop among Cambodians, but they can mainly be grown at the end of rainy season (October-January) that has temperatures around 21-25°C, but dry season cultivation (Feb-May) is often subjected to damages caused by extreme hot weather (40°C, April) and low fruiting rates. Cambodia is a country that has high temperature for growing tomato during summer session (October – April), 21 to 35°C (Cambodia's climate and weather, 2016). Laxman et al. 2013 reported that the optimal daily mean temperature for tomato fruit set under standard field conditions is between 21 and 27°C, so Cambodia is facing this problem. Some genotypes may be resistant to high temperature, but those genotypes have not been tested in Cambodia. The objective of this study was to investigate the agronomic traits and performance of some selected genotypes cultivated during high temperature period.

Methods

Experimental site and design

The experiment was located in the tropical climate zone with an average annual rainfall of 1400 mm (Solaw, 2011). The experiment was conducted at the Royal University of Agriculture during high temperature months between February to May, 2019 which was an off-season period for tomato production. This experiment was designed in Randomized Complete Block Design (RCBD) with three replications. The ten treatments were the tomato genotypes cultivated under open field condition at field crop station.

Genotypes

Heat-tolerant tomatoes are reported to have the ability to set fruits at higher temperatures than other tomatoes (AVRDC 2000). AVRDC tomato line CL5915-93D4-1-0-3 is a valuable source of heat tolerant-genes for tomato genetic improvement. Medium temperature for growth and reproduction is markedly different between crop species and their lines (Bohnert et al. 1995). Ten genotypes were cultivated in the experiment. Eight genotypes were obtained from AVRDC (Asian Vegetable Research and Development Center), Taiwan namely: CLN3736D, CLN3078G, CLN3212C, CLN3024A, CLN2498D, CLN3125L, CLN1621, CLN2026D) while other two local check varieties such as Neang Tamm and KK1 were obtained from the Cambodian Agricultural research and Development Institute (CARDI), 2006 and Kbal Koh Crop Station of Cambodia, respectively.

Growth performance of tomato Genotypes

CLN3736D, CLN3212C, CLN2898D are semi-determinate genotypes while the rest are determinate ones. The heat tolerance ranges from fair to moderate.

Temperature

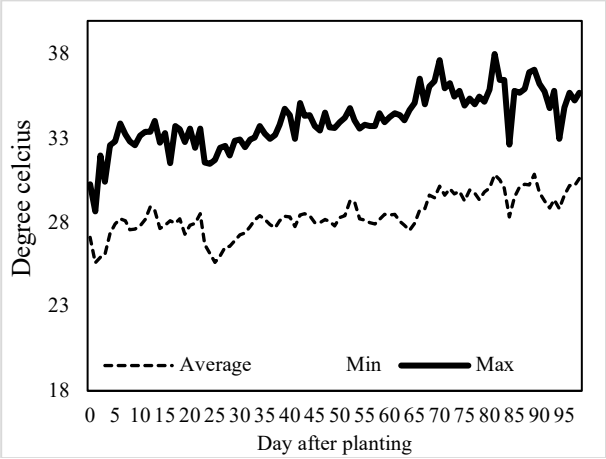

Fig. 1: Temperature during the whole crop cycle

Source: Weather station in crop station of Faculty of Agronomy, Royal University of Agriculture

The maximum temperature (24h) range from 30.70 to 37.5 °C. Sato and Peet et at. 2006 reported that 8-13 days prior to an thesis is the period most sensitive to moderately elevated temperature stress. It was very difficult to pollinate in tomato flowers because pollen has to move through small tube to reach stigma for fertilization. The distance between anther and stigma was also large which results in parthenocarpy fruit at heat stress condition. This means that it will effect tomato cultivation as the objective of this experiment. In this experiment, the maximum temperatures (24 hours) were recorded during the flowering stage in April at 37.5 °C.

Characteristics of experimental soil

The soil characteristics (0-30cm layer) were sandy loam with the pH of 7.1% and organic matter (SOM) of 1.01%. Addition soil characteristics were; total nitrogen (N) 0.03%; available phosphorus (P)32.7ppm; potassium (K) 1.01 cmol/kg; calcium (Ca) 4 cmol/kg; magnesium 1.6 cmol/kg; CEC 13.3 cmol/kg; EC 87.6 μS/cm; clay 18.1 %; silt 21.9 % and sand 60.0% (Soil laboratory of Royal University of Agriculture 2019).

Agronomic practices.

Plot at the open field. A recommended rate of N-P_2O_5-K_2O (75-30-100 kg ha^{-1}) was applied (CARDI, 2017). Cattle manure was applied to the plots and combined with minerals fertilizers before planting. The rate was then converted to the amount needed per plot. The cattle manure, all mineral P and K, and 50% of N were applied

as basal. The remaining 25% N was applied at the first flower blooming and 25% after the first fruit harvest.

Data collection sixteen plants per plot were chosen in each genotype and all replications. Data was recorded on reproductive growth where the scale based on flowers and fruits sunburns, rolling and sensitivity of individual plan of all tomato genotypes.

The land was plowed twice. Thirty plots were raised and were covered by rice straw, and cattle manure before 24-day old seedlings were transplanted in each.

Results

Table 1: morphological parameters of tomato genotypes.

Genotype	Days to flowering	No. of truss plant^{-1}	No. Flowers Plant^{-1}	No. Fruit plant^{-1}	Single fruit weight plant^{-1} (g)	Total fruit weight plant^{-1} (g)
CLN3736D	32.67	3.00 e	14.59 c	1.67g	13.98 d	19.06 f
CLN3078C	31.67	3.67 de	27.01 bc	7.67cde	38.79 bc	285.71 cd
CLN3212C	31.67	5.67 abc	21.71 bc	11.00b	43.23 b	449.84 bc
CLN3024A	32.00	3.67 de	21.44 bc	4.00fg	20.73 d	69.23 ef
CLN2498D	32.00	4.67 bcd	58.04b	7.00 def	44.68 b	313.14 cd
CLN3125L	32.67	3.67 de	25.36 bc	5.67 ef	40.91 b	225.17 de
CLN1621L	31.00	6.00 ab	56.53 b	22.67a	26.43 cd	585.77 b
CLN2026D	31.67	5.67 abc	50.26 bc	9.33bcd	39.83 bc	354.92 cd
Neang Tamm	30.67	4.33 cde	36.77 bc	8.00 bcde	39.42 bc	318.07 cd
KK1	31.67	7.00 a	106.49 a	10.67 bc	74.29 a	785.72 a
F (test)	ns	**	**	**	**	**
CV	3.77	18.50	5.68	20.26	20.67	27.08

The value in table followed by the different letter(s) indicated significant difference among treatments according to the least significant difference test, by Fisher's LSD test. ** Significant at P < 0.01, ns= non-significant.

According to the ANOVA analysis, it was non-significant among all genotypes of 100 % flowering. The average was observed at 32 days. There was a highly significant difference ($P \leq 0.01$) on number of truss per plant. KK1 is the highest among all genotypes with 7 trusses per plant. Moreover, the second higher are CLN1621L, CLN2026D and CLN3212C and CLN2498D with 5.25 truss per plant in average. However, the lowest number of truss was CLN3736D, CLN3078C, CLN3024A, CLN3125L, and Neang Tamm with 3 trusses per plant. On the other hand, there was a highly significant difference ($P \leq 0.01$) on the number of flowers per plant. The highest number of flowers was G10-kk1 with 106 flowers per plant. However, CLN2026D, CLN3078C, CLN3212C, CLN3024A, CLN3125L, and Neang Tamm had no significant difference in number of flowers per plant. CLN3736D was the lowest. For the number of fruits per plant, CLN1621L was the highest (23 fruits), followed by G10-kk1 and G3-CLN3212C with 11 fruits pe plant. Moreover, the third higher were CLN2026D, Neang Tamm, CLN3078C, with 20 fruits per plant in average. CLN2498D, CLN3125L and CLN3024A in average produced 18 fruits per plant. The lowest was CLN3736D, producing only 2 fruits per plant. Single fruit weight per plant was significantly different. KK1 was the highest in a single fruit weight followed by CLN3212C, G5-CLN2498D, CLN3125L. However, Neang Tom, CLN3078C, CLN2026D was the third highest with 39.34g/plant in average. The lowest are CLN3024A, CLN1621L, CLN3736D with 20.38g/plant. Total fruit weight of kk1was the highest at 785.72g. There was no significant difference between CLN3212C and CLN1621L. Furthermore, CLN2498D, CLN3078C, CLN2026D, Neang Tamm are the third highest (318.07g), followed by CLN3125L and CLN3024A. CCLN3736D was the lowest for fruit weight per plant with only 22.06g.

Table2: Physiological parameters of the 10 genotypes.

Genotype	Chlorophyll index reading	Biomass plant^{-1} (g)
CLN3736D	44.59	241.58 ab
CLN3078C	52.84	259.85 a
CLN3212C	51.34	227.73 ab
CLN3024A	51.23	152.35 bcde
CLN2498D	54.93	165.62 abcd
CLN3125L	58.86	168.59 abc
CLN1621L	56.71	68.57 de
CLN2026D	54.02	121.92 cde
Neang Tamm	69.31	68.21 de
KK1	46.51	57.58 e
F (test)	ns	**
CV	10.71	37.69

The values in table followed by the different letters indicate significant difference among genotypes using the least significant difference (LSD) test at P<*0.05*;** = *P<0.01*; ns= non-significant.

Chlorophyll index reading measured by a mobile SPAD-502 (Minolata Camer Co., Osaka, Japan) showed that it was not significantly different in each genotype with the average of 52.73. According to data analysis, biomass revealed significant difference among treatments. CLN3078C was the highest with 259.85g plant^{-1} followed by CLN3736D and CLN3212C. Moreover, it was not significantly different among CLN3024A, CLN2498D, and CLN3125L. CLN2026D, CLN1621L and Neang Tamm were non-significant

(86.90g plant-1) while the lowest was G10-kk1 with 57.58g plant^{-1}.

Discussion

High temperature adversely impacts on the tomato vegetative and reproductive phases and eventually decreases in yield (Abdul-Baki, 1991). The optimum daily mean temperature of tomato is between 21- 27^{o}C depending on the developmental stage (Geisenberg and Stewart 1986). The study illustrated that the KK1 and CLN1621L genotypes were the best while CLN3736D genotype was the worst in both morphological and physiological parameters.

A significant reduction in physiological parameters was observed for the number of trusses per plant, number of flowers per plant, and number of fruits per plant in all genotypes. The day to flowering (100%) and leaf chlorophyll index reading had non-significant difference among genotypes (Tables1 and 2). Chlorophyll is a green pigment that is found in the leaves and plays an important role in photosynthesis. The chlorophyll index reading is used to indicate the overall chlorophyll content of the leaves. One of the major factors illustrating leaf photosynthesis capacity and plant health is the content of chlorophyll (Jiang,2016). High temperature probably had not affect the day of flowering of tomato and leaf chlorophyll index. The variations of plant genetics in tomato genotypes have different abilities to resist high temperature (AVRDC, 2018). Thus, when there was no occurrence of abnormal characteristics, it means that it was not affected by high temperature.

The results in the present study showed that CLN1621L had the highest number of fruits per plant (23 fruits plant-1) followed by the second highest such as CLN3212C and KK1. The lowest was CLN3736D (2 fruits per plant). High temperature is known to cause drastic reductions in tomato flowering and fruit set (Abdelmageed et al. 2003). High temperatures would affect anthers development, especially in pollen development. Failure of fertilization after exposure to heat could attribute to decrease in pollen germination and pollen tube elongation (Dane et al. 1991). Anomalies in these tissues may be the reason why the amount of pollen produced under high temperature stresses decreases. Sexual reproduction in plants is more sensitive to high temperatures, resulting in a more adversely affected male gametophyte than vegetative growth. This phenomenon causes less fruit sets (Borghi and Fernie. 2020). Sato andPeet. 2006 also found the decrease in pollen viability due to high temperature. Although KK1 did not produce the maximum number of fruits, but it had the highest weight. In addition, CLN1621L also got high weight as well. KK1 had the highest fruit weight (785.72g pant^{-1}) and fruit diameter (53.89cm plant^{-1}) compared to other genotypes. CLN3736D was the lowest with 22.06g plant^{-1}. The difference in total fruit yield could be explained by the differences of fruits per plant, number of trusses per plant and number of flowers per plant. Higher amount of production supports a greater number of fruits per plant and higher number of trusses per plant. Higher total fruit yield per plant in open fields has also been reported in some previous studies (Yeshiwas et al. 2016). As a result, KK1 produced the highest single fruit weight (74.29g plant-1) compared to other genotypes, that is the reason why the amount of fruit weight of KK1 was the highest. Heat stress reduced fruit size (Integrated Pest Management, 2011).

Thus, KK1 might had been resistant to high temperature because it still produced big fruit while it was exposed to temperature. However, other genotypes set fruits, but fruit size was generally small and ripe early-cell expansion is inhibited. This experiment showed that the difference was recorded for biomass. CLN3078C genotype was the highest followed by CLN3736D and CLN3212C while the lowest was KK1 (57.58g). Dry matter was positively and strongly correlated with plant photosynthetic rates. According to Tadahisa et al. 2009, differences in dry matter content might be attributed to differences of light efficiency use among varieties and the availability of suitable climatic conditions that enhance photosynthetic capacity of these varieties.

In addition, tomato that produced maximum fruit weight, it has minimum biomass. This is due to the fact that nutrients were transported to every part of plants especially fruits. Moreover, there have been reports that the different genotypes or varieties have different biomass because it has different characteristics. In our study, CLN3078C produced many leaves and branches. More importantly it had many roots whereas KK1 had the lowest mass of leaves and branches. Biomass probably was not affected by high temperature.

Conclusion

On the basis of the results of the experiment, it can be concluded that fruit weight, number of flowers per plant, number of fruits per plant, and fruit size in plants increased at high temperature, KK1 genotype was the highest. Furthermore, CLN1621L and CLN3212C were the second highest because it also produced high yield. - KK1, CLN1621L and CLN3212C were found to be heat tolerant while the rest seven were heat sensitive. In contrast, CLN3736D was the genotype that cannot resistant to heat stress, because it produced the lowest yield. KK1, CLN1621L, and CLN3212C could be tolerant genotypes.

Fig. 2: The highest and the lowest yield of tomato genotypes.

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