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The Growth, Fruit Set and Fruit Cracking Incidents of Tomato Under Shade

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Abstract

Six tomato genotypes were grown in the field under full sun at 50% reduced light intensity using shading net to evaluate growth, fruit set, and fruit cracking incident. The experiment was conducted during the rainy season in December 2016 to March 2017 in Cikarawang Experimental Station, Bogor, Indonesia. The genotypes tested were sensitive ("Tora" and F7005001-4-1-12-5), tolerant (F7003008-1-12-10-3 and F7003008-1-12-16-2), and shade-loving (SSH-3 and "Apel Belgia"). The results showed 50% shading delayed flowering and harvesting time in all genotypes. Genotype and shading treatments had an independent effect on fruit set. Shaded plants had lower flower abortion and resulted in a higher number of fruits per harvest, except in "Apel Belgia" and "Tora" genotypes. Fruit cracking incidents were low under shading implying the use of shading can increase tomato quality. However, it needs further investigation through using natural shading, e.g., intercropping system before this finding is applied in farmers' field.

Keywords: *Solanum lycopersicum*, flower abortion, intercropping, low irradiance, quality

Introduction

Tomato (*Solanum lycopersicum* Mill.) is commonly planted in monoculture under full sun; however, in Indonesia, some farmers plant tomato under reduced light intensity in the intercropping system to optimize the land (Pranoto et al., 2013). The intercropping practice also has been widely adopted to minimize farming risks and to obtain additional income (Santosa et al., 2005a; 2005b; 2015; Upadhyay et al., 2010). In intercropping, lower strata plants generally receive lower light intensity due to shading by the upper strata.

The application of shading on tomato is not a new idea; it has both positive (Gent, 2007; Adeniyi, 2011) and negative effects (Russo, 1993; Sato et al., 2002). Positively, shading application in subtropical region advantages tomato quality under greenhouses to reduce excess heat (Peet and Willits, 1995; Matas et al., 2005; Gent, 2007; Bibi et al., 2012; Degri and Samalia, 2014). In the field, shading net application protects the plant from the impact of high wind speed, raindrops, minimizes insects and virus transmittances, and reduces incidents of blossom end rot and fruit crack (Teitel et al., 2008; Ben-Yakir et al., 2012; Masabni et al., 2016). Shade also reduces evapotranspiration to save water (Sorrentino et al., 1997).

In Indonesia, tomato production mainly is in open fields. The tomato productivity is usually determined by disease infection and fruit cracking (Aidawati et al., 2002; Wahyuni et al., 2014). The cracked fruits have a short shelf life and a low price in the market. Therefore, an effort to minimize the cracking incidents is important to sustain tomato production.

It has been known that fruit cracking in tomato is affected by the interaction between environmental and genetic factors (Dorais et al., 2001; 2004; Ehret et al., 2008; Ioannis et al., 2008; Wahyuni et al., 2014). Although breeding to obtain higher productivity in tomato for intercropping has been conducted in Indonesia (Wahyuni et al., 2014; Sulistyowati et al., 2016; Mustafa et al., 2017), physiological evaluation is still lacking. Sulistyowati et al. (2016) had concluded tomato genotypes into three groups, i.e., sensitive, tolerant and shade-loving. However, it is still unclear whether the fruit cracking is dependent on the shading tolerance of each group. The present study aims to evaluate tomato growth of different genotypes under full sun and 50% reduced irradiances, especially on fruit set and fruit cracking incidents.

Materials and Methods

The research was conducted at Cikarawang Experimental Farm, IPB University Bogor, Indonesia (240 m above sea level; -6.548882 S, 106.731570 E) during rainy season December 2016 to March 2017. The soil is a Latosol type. The soil was slightly acidic with pH (H_2O) 5.90. The soil had low status of total N, very low-status P and low-status K, i.e., 0.15%, 1.70 ppm and 0.26 me.100g^{-1}, respectively. Also, the status of C-organic was low (1.44%) and medium status of Ca (7.73 me.100g^{-1}). The average air temperature was 27.3–28.5 °C and air relative humidity 71–74%.

The experiment was arranged in nested design with two factors, i.e., shading as main plot (full sunshine and 50% reduced light intensity) and six tomato genotypes as a subplot, i.e., sensitive (“Tora” and F7005001-4-1-12-5 [F755]), tolerant (F7003008-1-12-10-3 [F733] and F70030081-12-16-2 [F732]), and shade-loving (SSH-3 and “Apel Belgia” [AB]). The genotype of tomatoes used in present experiment is the IPB University collection after classification for shading tolerance by Sulistyowati et al. (2016). All genotypes are a determinate group, and the fruit is cherry tomatoes except “Tora” and F755 as salad and beef tomatoes, respectively. The subplot was replicated three times.

Tomato seeds were sown in the plastic seedling tray containing 45 holes with individual cells of 5 cm x 5 cm x 10 cm. Seedling media was a mixture of organic manure, rice husk charcoal and soil (1:1:1, v/v); and the seedling was planted at 30 days after sowing. The seedling size was 20±2 cm in height with 4-5 leaves was planted at a distance of 50 cm × 70 cm in a raised bed. A planting bed sized 1.2 m × 5 m plot is suitable for 20 plants; each replication consisted of 3 beds for 60 plants. At planting, 0.5 kg goat manure was applied. For measurement, 5 plants were selected randomly in each replication. Two compound NPK fertilizers, N-P-K 15-15-15 and 10-55-10, were applied at a total of 8.8 g per plant, or ~755 kg NPK ha^{-1}. The fertilizers were applied in solution and separated into six times application with interval two weeks. Each plant received 200 mL for each application starting 2nd week after planting (WAP). At the vegetative stage (2-8 WAP) NPK (15-15-15) was dissolved at 10 g.L^{-1} and at the generative stage (10-12 WAP) the NPK (10-55-10) was at 2 g.L^{-1}. Watering was applied if rainfall of the previous day was less than 3 mm. During flowering and fruiting, the watering was applied twice a day, in the morning and afternoon.

Fruit set was counted relative to total flower inflorescence. The fruit was harvested at a mature stage after $\geq$ 60% fruit skin turned red (IPGRI 1996). Fruit cracking was evaluated at harvest by ‘present’ or ‘absent’, irrespective of the cracking size. Data were analyzed using F test, and significant means between treatments were further separated using least significant difference (LSD) α=5%.

Results and Discussion

Vegetative Growth and Sugar-starch Content

There was no significant difference in stem diameter among tomato genotypes within a particular shade level (Table 1). Shade-loving and shade-tolerant genotypes tended to have smaller stem diameter under shading treatment. Plant height increased by 50% shading treatment, irrespective of genotype group. This phenomenon has been reported in Solanaceae members (Boyd and Murray, 1982; Bibi et al., 2012; Masabni et al., 2016) and other families (Santosa et al., 2006; Polthanee et al., 2011) due to auxin action (Roig-Villanova et al., 2007).

There was no interaction between shading and genotypes on leaf number and total leaf area. Shading at 50% decreased the number of leaves, and the “Tora” genotype produced the lowest number (Table 2). The individual leaf area increased at 50% shading, however, the total leaf area was nearly equal among genotypes. At 50% shading, the tomato plant produced 43 leaves with total leaf area of 148.7 cm^2, while under 0% it had 63 leaves with 115.9 cm^2. Leaf size expanded nearly two folds at 50% shading (3.46 cm^2/leaf) than the leaf under 0% shading (1.84 cm^2/leaf). Increasing leaf size is a common phenomenon for plants growing under shaded conditions (Roig-Villanova et al., 2007; Sulistyowati et al., 2016).

Leaves of all tomato genotypes had higher starch content at low irradiance, while sugar content was constant across shading levels (Table 2). The correlation between genotype and shading on starch and sugar status in the leaves was not significant, although plants under 50% shading had a higher sugar-starch ratio than those of control (Table 3). Table 3 shows F755 and AB had the highest ratio under 50% shading. Sugar-starch ratio increased markedly in shade-loving genotypes under 50% shading than the sensitive genotypes such as “Tora”. Interestingly, F755 as a sensitive genotype had a different response to "Tora". Each genotype likely had a different response against shading treatments.

Flowering and Fruit Set

There was an interaction between shade and genotype on flowering time. Shading delayed flowering time by 1-2 days in all genotypes, except "Tora" (Table 4). The "Tora" tended to flower earlier in shade than in control in contrast to the finding of Sulistyowati et al. (2016). In soybean, Bing and Ning (2015) stated that 25% shading delay flowering, while Polthanee et al. (2011) noted that tolerant varieties flower earlier at 50% shading. The flowering time of "Tora" under

Table 1. Stem diameter and plant height of tomato genotypes under control (0%) and 50% shading at 7 weeks after planting

Genotype	Stem diameter (mm)[z]		Plant height (cm)	
	0%	50%	0%	50%
AB (SL)	12.5±2.6 a	8.9±0.5 a	76.7±7.6 bcd	91.0±2.7 abc
SSH-3 (SL)	13.4±1.4 a	10.4±1.3 a	65.7±2.5 cd	87.7±5.0 abc
F733 (T)	12.6±2.4 a	10.1±1.2 a	96.3±5.5 ab	110.7±23.9 a
F732 (T)	11.7±0.5 a	9.9±0.4 a	74.7±4.2 bcd	108.0±8.5 a
"Tora" (S)	10.7±1.0 a	10.9±2.3 a	57.3±10.6 d	86.3±3.8 abc
F755 (S)	11.2±0.9 a	11.5±0.0 a	68.0±3.6 cd	113.0±13.0 a

Note: Data are means±SE; different letters represent statistically significant differences ($P<0.05$); S: Sensitive, T: Tolerant, SL: Shade-loving genotype. [z]Measured at 10 cm above the soil surface.

Table 2. Number and total leaf area, starch and sugar content of tomato leaves under 0% and 50% shading

Treatment	Leaf number[z]	Leaf area (cm^2)[z]	Starch content (%)[y]	Sugar content (%)[y]
Shade				
0%	63±29 a	115.9±46.0 a	4.51±1.62 b	6.47±1.50 a
50%	43±16 b	148.7±64.0 a	7.57±0.77 a	5.77±1.13 a
Genotype				
AB (SL)	64±5 a	150.5±48.6 a	5.71±1.61 a	5.79±2.19 a
SSH-3 (SL)	62±19 a	151.4±51.9 a	5.49±2.78 a	6.80±1.16 a
F733 (T)	65±28 a	131.9±34.2 a	6.89±1.39 a	6.90±0.61 a
F732 (T)	64±28 a	132.9±66.2 a	5.67±1.99 a	6.96±0.44 a
"Tora" (S)	16±4 a	102.5±63.6 a	6.16±0.64 a	4.78±0.77 a
F755 (S)	46±11 a	124.7±58.2 a	6.33±2.47 a	5.49±0.87 a

Note: Data are means±SE; different letters represent statistically significant differences ($P<0.05$); S: Sensitive, T: Tolerant, SL: Shade-loving genotype. [z]Full expanded leaves measured at 7 WAP; [y]Measured from leaves at 9 WAP.

Table 3. Starch and sugar ratio in tomato genotypes under control (0%) and 50% shading

Genotype	Starch-sugar ratio		Increase in ratio (%)
	0%	50%	
AB (SL)	0.61±0.15 f	1.69±0.01 a	177.05
SSH-3 (SL)	0.46±0.15 f	1.19±0.09 bcd	158.70
F733 (T)	0.77±0.14 def	1.25±0.10 bc	62.34
F732 (T)	0.56±0.14 f	1.09±0.03 cde	94.64
"Tora" (S)	1.29±0.01 abc	1.30±0.15 abc	0.77
F755 (S)	0.69±0.32 ef	1.59±0.13 ab	130.43

Note: Data are means±SE; different letters represent statistically significant differences ($P<0.05$); S: Sensitive, T: Tolerant, SL: Shade-loving genotype shading was probably unstable, thus time to flower was a less suitable characteristic for evaluating this tomato genotype in response to shading especially for “Tora”.

Fruit set was 81.64% or larger, irrespective of shading levels and genotypes, with “Tora” genotype as an exception (Table 5). Fruit set in “Tora” was 50.39% in the control treatment and 77.77% under 50% shading but statistically similar. Except for the “Tora”, shading treatment promoted tomato fruits set. At 50% shading, the temperature was 0.4-2.8 °C lower and air relative humidity was 2.7-4.7% higher than that under full sunshine. It is probable that increasing fruit set at 50% shading due to the higher level of air humidity and lower temperature. The average daily temperature was 28.50 °C and 27.30 °C while relative humidity was 70.88% and 73.88% for control and 50% shading, respectively. Huang et al. (2011) mentioned that air humidity $\geq$ 70% promotes pollen germination and fertilization.

Table 5 shows that the number of flower clusters per plant was significantly affected by genotype and shading treatments. It seems that tomato plants had a lower ability to produce flower clusters under shading, with the exception of sensitive genotypes “Tora” and F755. Both genotypes were able to maintain a similar number of flower clusters under full sun and 50% shading. Moreover, the number of flowers and fruits in each cluster was determined by the genotype not by the shade (Table 6). Among the genotypes, “Tora” had the lowest number of flower and fruit per cluster, i.e., 4.5 and 2.9, respectively. Yulianti et al. (2018) noted that *Solanum nigrum* produces 191 flower clusters under full sunshine but 98 clusters under 50% shading, decreasing by 49%.

Flower drop was lower under 50% shading, irrespective of genotypes (Table 6). Flowers located at the upper, middle and lower parts of a flower cluster had the same chance to drop. The flowers rarely dropped before anthesis in both shading treatments. Flower abortion during and after anthesis at full sunshine treatment seemed to coincide with heavy precipitation incidents. The lower flower drop under shading was probably due to physical protection by net from the direct impact of rainwater, as has been stated by Masabni et al. (2016).

Table 4. Flowering and harvesting time of tomato genotypes under 0% and 50% shading

Genotype	Flowering time (day)^{y}		First harvesting time (day)^{z}	
	0%	50%	0%	50%
AB (SL)	22±1 de	24±1 cde	65±1 ef	67±1 c
SSH-3 (SL)	21±0 e	23±0 cde	63±1 g	65±1 de
F733 (T)	24±1 cde	24±1 cde	65±1 ed	66±1 cd
F732 (T)	22±0 de	24±1 cd	63±1 fg	68±1 c
“Tora” (S)	29±1 a	28±1 ab	72±1 b	78±1 a
F755 (S)	25±0 cd	26±1 bc	67±1 c	73±1 b

Note: Data are means±SE; different letters represent statistically significant differences (P<0.05); S: Sensitive, T: Tolerant, SL: Shade-loving genotype. ^{Y}At least 50% of plants have flowered (IPGRI 1996), ^{Z}At least 50% of plants have one ripe fruit (IPGRI 1996).

Table 5. Fruit set and number of flower cluster per plant of tomato genotype grown under control (0%) and 50% shading

Genotype	Fruit set (%)		Flower cluster/plant	
	0%	50%	0%	50%
AB (SL)	85.67±2.73 a	83.79±2.66 a	21.0±7.6 a	10.4±1.4 bc
SSH-3 (SL)	81.64±8.26 a	86.12±5.72 a	14.1±1.4 abc	9.6±0.2 bc
F733 (T)	86.89±4.51 a	86.28±0.94 a	17.7±4.6 ab	10.2±0.5 bc
F732 (T)	88.41±1.97 a	88.33±3.10 a	18.2±2.9 a	11.2±2.0 abc
“Tora” (S)	50.39±5.01 b	77.77±22.2 ab	5.0± 0.9 c	6.0±6.5 c
F755 (S)	85.46±1.31 a	85.35±9.29 a	11.3±1.0 abc	12.7±2.4 abc

Note: Data are means±SE; different letters represent statistically significant differences (P<0.05); S: Sensitive, T: Tolerant, SL: Shade-loving genotype.

Although 50% of shading reduced flower drop, the number of fruit per harvest was similar among 0% and 50% shading treatments (Table 7). Table 7 shows that the number of fruit per harvest was determined by genotypes, consistent with flower data as stated in Table 6. Among genotypes, “Tora” produced the lowest number of fruit in each harvesting cycle, while AB and SSH-3 produced the highest.

Yield and Fruit Cracking

There was an interaction between shade and genotype on harvesting time (Table 4). The tomato required 63-72 days from transplanting until ready for the first harvest. Under 50% shading, the first harvesting was delayed 5-7 days for sensitive genotypes and 1-4 days in delay for tolerant and shade-loving genotype groups. It means that growth and fruit maturation was slightly delayed under shading, irrespective of genotypes.

Total fruit production decreased by shading treatment, 25.8 t ha^{-1} at 0% shading into 19.6 t.ha^{-1} at 50% shading, irrespective of the genotypes (Table 7). Among genotypes, there was no significant difference in total fruit production. This finding is in contrast to Sulistyowati et al. (2016) where shade-sensitive groups “Tora” and F755 exhibit marked yield reduction at 50% shading as compared to other genotypes. Inconsistent effects of reduced light intensity on tomato production has been reported by Russo (1993). The inconsistency might arise from genetic properties such as different physiological responses to photoinhibition. Sorrentino et al. (1997) and Demmig-Adams and Adams (2003) noted that temperature and environmental conditions determine

Table 6. Number of flower and fruit per cluster, fruit cracking and flower drop of tomato genotypes grown under 0% and 50% shading

Treatment	No. flower/ cluster	No. fruit/ cluster	Flower drop (%)	Fruit cracking (%)^z
Shade				
0%	7.0± 1.0 a	4.9±1.3 a	15.34±6.37 a	31.99±18.24 a
50%	5.9± 0.9 a	5.0±1.0 a	7.22±2.67 b	21.93±12.40 a
Genotype				
AB (SL)	6.6±0.8 a	5.4±1.1 a	19.84±6.27 a	35.38±2.62 ab
SSH-3 (SL)	6.8±0.7 a	5.7±0.6 a	19.50±8.41 a	48.23±3.73 a
F733 (T)	6.0±0.5 a	5.2±0.4 a	18.00±9.19 a	20.99±5.03 abc
F732 (T)	6.0±0.5 a	5.3±0.4 a	14.33±4.83 a	40.89±6.57 ab
“Tora” (S)	4.5±0.6 b	2.9±0.9 b	10.17±7.31 a	5.56±3.73 c
F755 (S)	5.8±0.6 a	4.9±0.5 a	9.83±0.55 a	11.66±7.36 bc

Note: Data are means±SE; different letters represent statistically significant differences (P<0.05); S: Sensitive, T: Tolerant, SL: Shade-loving genotype. ^{z}Counted from total harvest.

Table 7. Number of fruit per harvest per plant and total production of tomato genotypes grown under 0% and 50% shading

Treatment	Average number of fruits per harvest	Total production (ton.ha^{-1})^z
Shade		
0%	14.7±7.6 a	25.8 a
50%	16.8±8.1 a	19.6 b
Genotype		
AB (SL)	22.7±5.0 a	26.4 a
SSH-3 (SL)	22.6±2.4 a	25.7 a
F733 (T)	15.6±4.8 abc	23.7 a
F732 (T)	18.1±5.3 ab	16.3 a
“Tora” (S)	5.3±0.2 c	25.2 a
F755 (S)	10.1±5.7 bc	19.2 a

Note: Data are means±SE; different letters represent statistically significant differences (P<0.05); S: Sensitive, T: Tolerant, SL: Shade-loving genotype. ^{z}Population for one hectare: 85,714 plants.

the degree of photoinhibition. Another factor is stated by Ulinnuha et al. (2019) that some tomato genotypes under shading produce smaller fruit numbers with large in size or larger fruit number but smaller in size than those under the full sunshine.

Shading treatment interacted with genotype in affecting fruit cracking incident. Fruit cracking tended to decrease under shading (Table 6). In general, control plants severed fruit crack at rate 4.63–48.23% depending on the genotype. Three genotypes, i.e., F755, F733, and "Tora" had a high cracking incident on at full sun treatment; and the incident decreased markedly under shading by about 35% (Figure 2). Here, cracking was shaped concentric and radial (Figure 1). "Tora" predominantly had radial, while F755 had both patterns.

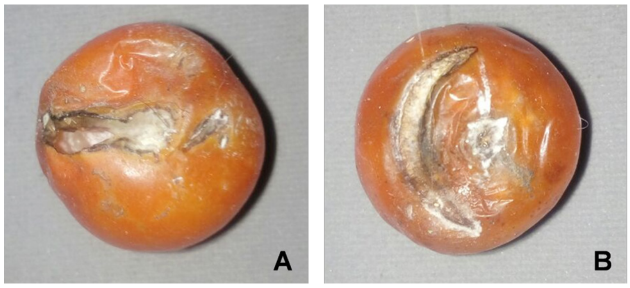

Figure 1. Typical of radial (A) and concentric crack (B) on tomato fruit of F755 genotype; both cracks are infected by *Alternaria solani*

In general, the tomato fruit cracking incident is evaluated based on the scenario of soil water fluctuation (Guichard et al., 2001), Ca level (Liebisch et al., 2009) and air temperature (Emmons and Scott, 1998). In the present study, the correlation

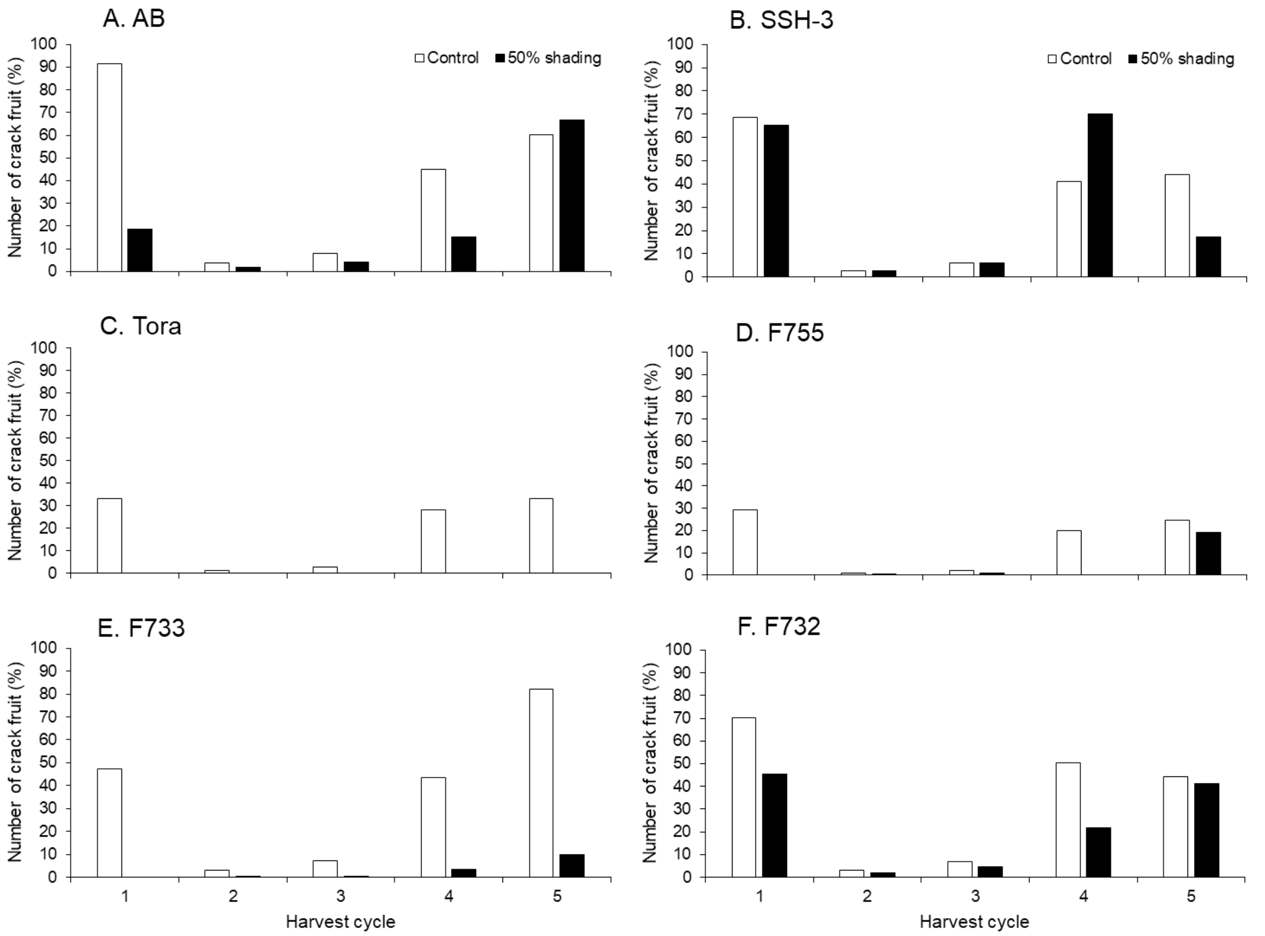

Figure 2. Percentage of cracked fruits of six tomato genotypes in each harvest cycle under full sun and 50% shading.

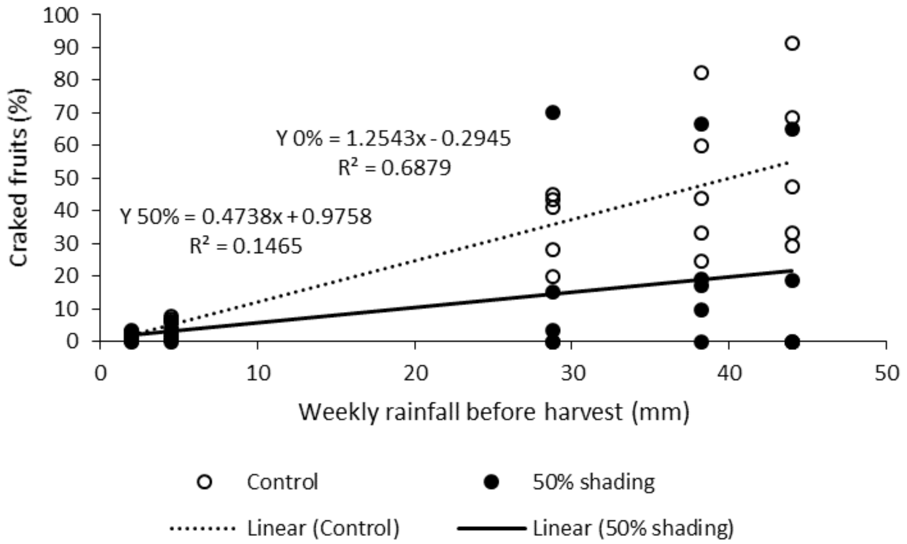

Figure 3. Correlation between total weekly precipitation and incident of cracked fruits of six tomato genotypes in all harvest cycles under full sun and 50% shading.

test between weekly rainfall and cracking incident showed a significant effect but the correlation value was low for 50% shading (Figure 3). It means that rainfall contributed to the fruit crack at control treatment, but less likely at reduced-light intensity. In the open field, high fruit cracking incidence perhaps was due to high rain intensity; the cracking is usually concentric but could be russeting after high rain. All plots were supplemented with irrigation thus soil water fluctuation was minimized. Previously, Ikeda et al. (1999) evaluated water stress tomato reveals that low water pressure inside the plant lead to low fruit cracking. Thus, it is also possible that in control treatment, low shading caused transpiration rate was maintained high leading to high water pressure inside the plants, and the plant removing the excess water through fruit cracking.

Calcium evaluation showed that the incident was unlikely related to its level in fruits. The contrast test based on calcium level on the fruit of SSH-3 and "Tora" showed no significant differences, i.e., 2.04±0.04 and 1.59±0.17 me.100 g^{-1} at full sunshine and 2.01±0.05 and 1.53±0.20 me.100 g^{-1} at 50% reduced light intensity, respectively. It is interesting to evaluate different level of Ca application on the cracking incidence under shading pressure.

Among the factors, air temperature could be the most probable factor that affected cracking at 50% shading. During the daytime, air temperature at full irradiance was recorded at 28.50 °C while under shading is always 1.2–2.3 degrees lower. Many fruits under full sunlight had severe sunburn symptoms. The possible contribution of temperature and light intensity on tomato cracking in present study followed the finding of Khadivi-Khub (2015).

It is likely that tomato genotype contributes in fruit cracking incident in present experiment, as stated by Capel et al. (2017). Nevertheless, it is still difficult to conclude a single factor determined the cracking incident under shading. It is interesting to further evaluate genetic and environmental factors in fruit cracking by following common hypotheses (Peet and Willits, 1995; Ehret et al., 2008; Mustafa et al., 2017). In the future, possible factors that might contribute on tomato fruit cracking such as level of irrigation, high relative air humidity and canopy manipulation like toping and pinching, could be tested in relation to genotype screening for fruit cracking resistance.

The present study demonstrated that tomato genotypes under shading expressed differential responses on fruit set, production and fruit cracking. Four out of six genotypes exhibited an inconsistent response to 50% shading on characters of fruit production. In the farmer's field application, such a flexibility response becomes a disadvantage. Thus, it is interesting to evaluate a larger number of tomato genotypes to establish suitable genotypes for supporting the intercropping system in Indonesia.

Conclusions

Reduced light intensity by 50% reduced growth and yield components of tomatoes, but tolerant genotypes expressed more marked reduction. Reduction in the amount of flowers was compensated by decreasing in flower abortion under 50% shade, resulting in an increase in the number of fruits per harvest except in "Apel Belgia" and "Tora" genotypes. In this study, shading at 50% tended to reduce fruit cracking in all genotypes. It implies that the genotype recommendation for intercropping needs further evaluation in the field.

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