Character Selection of Shade-Loving Tomatoes and Genetic Interaction X Shade Level on Tomato Plants Productivity

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Abstract. Low light stress causes a variety of changes in morphology, anatomy, and phenology, these changes are intended to capture more photons in low light. This study consists of two experiments, the aim (1) this study was to investigate morphology, anatomy, and phenology characters of shade-loving tomato genotypes at low light intensity; and (2) the genetic interaction and shade level on the yield of tomato plants. The experiment was carried out from January 2016 to October 2019, arranged in a nested design in the form of 2 factors (shade level and tomato genotype) with 3 and 4 replications. The first factor consisted of two types of shade, namely without shade (0%) and 50% shading (first experiment), added corn shade, and papaya shade (second experiment). The tomato genotypes used in the first experiment consisted of four shade-loving genotypes (SSH 3, Medan 4, Papua 2, Maros 3), four shade-tolerant genotypes (Karina, Tomat kecil 1, SSH 9, Bogor), and four shade-sensitive genotypes (Kediri 2, Brastagi 6, Marglobe, F 6005001-4-1-12-5). The second experiment consisted of a shade-loving genotype (SSH3), a shade-sensitive parental genotype (4979), five cross-breeding genotypes (370-1, 384-11, 326-4, 380-16, and 381-11), and three commercial varieties (IPB Tora, Karina, and Palupi). The first experimental results of shade-loving tomato genotypes at low light intensity showed an increase in plant height, leaf number, maintaining high stomata density, reducing leaf thickness and palisade height, and flowering time and harvesting time. The second experiment results showed that genotypes 370-1 and 384-11 were 50% shade-loving genotypes, had better production than commercial varieties. Genotypes 380-13, SSH3, and 4979 were shade-loving papaya genotypes, tomato genotypes 326-4, 380-16, and 381-11 were shade-loving maize genotypes; and has a production that tends to be better than commercial varieties.

Keywords: Leaf thickness · Stomata density · Low light intensity · Papaya shade · Corn shade

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1 Introduction

Plants form several adaptation mechanisms to adapt to environmental stresses in the long-term evolutionary process. Lack of light causes different effects on plant genotypes, due to changes in morphological reconstruction. Low light stress causes plants to undergo various morphological changes, such as decreased leaf and mesophyll thickness, taller stems, thinner leaves, longer flowering, and harvesting ages [1–4], decreased stomatal density [5], increased leaf number [2, 3, 6]. This morphology aims to capture more photons at low light.

The light intensity will affect the shape and leaf anatomy, including epidermal cells and mesophyll cells [7]. Plants that are in shaded conditions usually show a reduction in the palisade layer and mesophyll cells which causes the leaves to form wider and thinner [8, 9]. The palisade layer can change according to light conditions, which causes plants to be efficient in storing light energy [10]. This is evident from several agricultural products such as: Increased soybean leaf area at several shade levels compared to control [11–14]. An increase in leaf area is also known to occur in the leaves of *Pisum sativum* L. [15]. This study consisted of two experiments, the objectives of (1) knowing the morphological, anatomical, and phenological characters of the shade-loving tomato genotype at low light intensity; and (2) the interaction of genetics and shade level on tomato yield.

2 Material and Methods

The study was conducted from January 2016 to October 2019 in Bogor, West Java, Indonesia. The study consisted of two experiments, arranged in a nested design with 2 factors (genotype as subplot and shade level as main plot), with 3 and 4 replications. The first factor consisted of two shade levels, namely no shade (0%) and 50% shade (first experiment), the addition of corn shade, and papaya shade (second experiment). The tomato genotype used in the first experiment consisted of 12 genotypes (which were selected genotypes from 50 genotypes and had been tested from previous experiments) [16, 17], in the form of four shade-loving genotypes (SSH 3, Medan 4, Papua 2, Maros 3), four shade-tolerant genotypes (Karina, Tomato Kecil 1, SSH 9, Bogor), and four shade-sensitive genotypes (Kediri 2, Brastagi 6, Marglobe, F 6005001-4-1-12-5). The second experiment consisted of one shade-loving genotype (SSH3), one shade-sensitive parental genotype (4979), five crossbred genotypes (370-1, 384-11, 326-4, 380-16, and 381-11), and three comparison genotypes (Tora IPB, Karina, and Palupi). Tomato cultivation activities are carried out according to standard tomato cultivation.

2.1 Experiment 1

Seeds of 12 genotypes of tomatoes were sown on a seedling tray. Furthermore, tomato seedlings aged 25 days after sowing were planted on beds with a spacing of 50 cm × 50 cm, under paranet with 50% shade intensity and no shade (0%) as a control. Observations included plant height, leaf number, leaf area, stomatal density, leaf thickness, and palisade height, flowering time, and harvesting time. Analysis based on F test at = 5% or = 1% if significantly different followed by contrast test, using SAS software version 9.1.3.

2.2 Experiment 2

Planting tomatoes in the shade of corn was carried out between rows of corn (100 cm × 50 cm) with a spacing of 50 cm × 50 cm (two rows of tomatoes between 2 rows of corn). Corn planting is carried out at the same time as transplanting tomatoes. Tomato planting in papaya shade was carried out between papaya rows (2.5 m × 2.5 m) with a spacing of 50 cm × 50 cm (4 rows of tomatoes between 2 papaya rows). When transplanting tomatoes, papaya plants are 4 months old after planting. Observations were made on light intensity: leaf greenness, leaf width, leaf area, fruit set, and characters genetic analysis. The analysis uses variance analysis if it has a significant effect at the 5% level, further BNJ testing is carried out at the 5% level. Data analysis was performed using Microsoft Excel and PKBT STAT 2.2 software.

3 Results and Discussion

3.1 Experiment 1: Morphological, Anatomical, and Phenological Characters of Shade-Loving Tomatoes Genotypes at Low Light Intensity

3.1.1 Morphological Characters

Leaf area was affected by single factor shading treatment, while leaf number was not affected by single factor shading treatment or genotype group. Shade 50% did not result in an increase in the leaf number in all genotype groups. Cabuslay et al. [18] reported that shade-tolerant rice plants tend to elongate and increase plant height, number, and leaf area. Leaves are the main photosynthetic organs for plants that are directly involved in the process of capturing light by converting light energy into chemical energy to form photosynthesis [10].

Shade significantly affected leaf area (Table 1). The increase in leaf area in the 50% shade more than doubled, namely, in the shade-loving group, it increased by 112.60% and tolerance 117.76%, while the sensitive group was only 59.08%. Observation of leaf area under 50% shade conditions showed an increase in leaf area of tomato plants more than doubled [19]. The mechanism of avoiding low light intensity has been proven from several research results such as: increasing soybean leaf area at several shade levels compared to controls [5, 20], as well as in upland rice [1–3].

Increased leaf area higher makes the area of light capture per plant is higher. So that the increase in light that can be absorbed by the leaves of the genotype is high, even though there is a light deficit. Changes in the morphological characteristics of tomato genotypes in shade conditions are related to the tolerance of plant adaptation to shade. In this case, it is the response of increasing light capture area in shade-loving genotypes by increasing plant growth components (plant height and leaf area) which are higher than sensitive.

The provision of 50% shading causes the intensity and distribution of light obtained by plants to be lower than those that receive full light. The plants respond to low light changes in phytohormones that regulate the phytochromes balance, especially changes in the content of ethylene, gibberellins, and auxins, resulting in stem and stalk elongation [21, 22]. Chozin et al. [23] also reported that the increase in rice plant height varied

Table 1. Test of 3 tomato genotype groups for plant growth characters at 0% and 50% shade

Treatment	Shading		Changes (%)	Contrast Test
	0%	50%		
Genotypes:	-------Plant height (cm)------			
• Loving-shade	58.08 b	83.80 a	(144.28)	**
• Tolerant-shade	62.73 ab	80.58 b	(128.45)	**
• Sensitive-shade	66.58 b	86.05 a	(129.24)	**
Genotypes:	---------Leaf number---------			
• Loving-shade	40.83	47.18	(115.55)	tn
• Tolerant-shade	42.50	49.67	(116.86)	tn
• Sensitive-shade	44.35	47.53	(107.18)	tn
Genotypes:	-------Leaf area (cm^2)-------			
• Loving-shade	35.52	75.52	(212.60)	**
• Tolerant-shade	41.05	89.38	(217.76)	**
• Sensitive-shade	40.38	64.24	(159.08)	**

Note: Numbers in brackets are relative values to control values (0% shade) and different letters in the same column in the same treatment, mean significantly different or very significant based on the contrast test = 5% or = 1% tn = no significant, *) significant based on F test = 5%, **) very significant based on F test = 1%.

between genotypes in the shaded environment, but generally tolerant genotypes had a greater ability to increase plant height than sensitive genotypes.

This adaptation response is an effort of shade-loving tomato genotypes to obtain more light when growing in light deficit conditions in order to be able to maintain high photosynthetic processes. The plant height of this genotype, which exceeds other genotypes, is balanced with the formation of better photosynthetic organs and apparatus, making the rate of photosynthesis remain high. A high rate of photosynthesis will result in high assimilation, which ultimately results in high yield and yield components as well.

3.1.2 Anatomical Characters

Shade 50% reduced stomatal density, leaf thickness, and palisade height in all genotype groups, namely shade-loving, tolerant and sensitive (Table 2). Sasmita [2] stated that shade-tolerant upland rice when shaded resulted in a higher number of stomata, thus allowing the supply of CO_2 per photosynthetic unit to be higher, resulting in increased photosynthesis. Pertiwi et al. [5] added that higher stomatal density indicates a greater CO_2 diffusion capacity in tolerant soybean genotypes. The more and wider the stomata opening, the higher the CO_2 gas exchange. This indicates that the shade-loving genotype has a higher ability to carry out photosynthesis than the tolerant and sensitive genotype.

Table 2. Test of 3 tomato genotype groups for leaf anatomical characters at 0% and 50% shade

Treatment	Shading		Changes (%)	Contrast Test
	0%	50%		
Genotypes:	---Stomata density (mm^{-2})---			
• Loving-shade	13.27 b	11.91 a	(89.76)	**
• Tolerant-shade	14.00 a	11.45 a	(81.79)	**
• Sensitive-shade	13.52 b	9.26 b	(68.57)	**
Genotypes:	----Leaf thickness (nm)----			
• Loving-shade	192583 a	130047 a	(67.53)	**
• Tolerant-shade	163664 b	118107 b	(72.16)	**
• Sensitive-shade	162101 b	132043 a	(81.46)	**
Genotypes:	----Palisade height (nm)----			
• Loving-shade	75247 a	51121 a	(67.94)	**
• Tolerant-shade	64742 b	43249 b	(66.80)	**
• Sensitive-shade	58383 c	46601 ab	(79.82)	**

Note: Numbers in brackets are relative values to control values (0% shade) and different letters in the same column in the same treatment, mean significantly different or very significant based on the contrast test = 5% or = 1% tn = no significant, *) significant based on F test = 5%, **) very significant based on F test = 1%.

Leaf thickness and palisade height of the happy genotype group when fully illuminated were the highest, but when shaded they showed no difference from other genotypes. Leaf thickness and palisade height at 50% shade conditions for shade-loving and tolerant genotypes showed a higher percentage of decline than sensitive genotypes (Table 2). The decrease in leaf thickness and palisade height was inversely proportional to the increase in leaf area. The higher the increase in leaf area of a plant genotype, the higher the decrease in leaf thickness and palisade height. The percentage increase in leaf area of the happy and tolerant genotype groups was higher, resulting in a decrease in leaf thickness and higher palisade height. Broader and thinner leaves in shaded conditions are caused by thinning of the palisade layer and mesophyll cells which causes plants to become more efficient in storing energy for development [8, 10, 24]. According to the findings of Sasmita [2], leaf thickness and mesophyll cell size of tolerant upland rice genotypes were lower than those sensitive to 50% shade. Baharuddin et al. [19] added that 50% shading resulted in a decrease in tomato leaf thickness by up to 25%.

Factors thought to be involved in influencing the morphology (leaf area) of tomato genotypes when shaded include the palisade layer. The thinning of the palisade layer causes the leaves to become thinner, resulting in an increase in leaf area. The leaf anatomy of the happy and shade-tolerant genotypes had a thinner leaf mesophyll so that the leaf thickness was thinner. This character is related to its ability to intercept light more efficiently. Genotypes happy and tolerant have broad leaves and thinner will make this genotype efficient in absorbing light energy when growing in the shade. The tolerance

Table 3. Test of 3 tomato genotype groups for phenological characters at 0% and 50% shade

Treatment	Shading		Changes (%)	Contrast Test
	0%	50%		
Genotypes:	----Flowering time (DAP)---			
• Loving-shade • Tolerant-shade • Sensitive-shade	40.12 b 37.70 b 40.82 a	41.82 a 39.63 c 40.40 b	(104.24) (105.13) (98.98)	tn tn tn
Genotypes:	-----Harvesting time (DAP)-----			
• Loving-shade • Tolerant-shade • Sensitive-shade	57.83 b 57.08 ab 59.08 a	61.83 a 60.58 ab 60.02 b	(106.92) (106.13) (101.59)	** ** **

Note: Numbers in brackets are relative values to control values (0% shade) and different letters in the same column in the same treatment, mean significantly different or very significant based on the contrast test = 5% or = 1% tn = no significant, *) significant based on F test = 5%, **) very significant based on F test = 1%.

of plants to shade is determined by their ability to carry out the normal photosynthesis process when shaded.

3.1.3 Phenological Characters

The results of the contrast test for shaded plants (50%) showed a very significant difference between genotype groups in harvesting age and not significant in flowering age (Table 3). If the distance between flowering age and harvest time is related, the shade-loving genotype group tends to be longer in shaded conditions, compared to other genotype groups. The shade-loving group experienced a longer fruit formation/filling time than when grown without shade. The prolongation of harvest age after flowering in the shade-loving group was probably related to the ability of plants to increase chlorophyll content and maintain the greenness of the leaves in shaded conditions. This greenness condition spurred shade-loving genotypes to carry out photosynthesis until the end of their growth. Following the statement that shade-tolerant upland rice showed a longer flowering and harvesting age than sensitive genotypes [1, 3].

3.2 Experiment 2: Tomato Genotypes and Different Type of Shades Interaction on Tomato Crop Yield

3.2.1 Microclimate in Different Type of Shades

The results showed that there were differences in the microclimate in different type of shades. Sweet corn shading resulted in 2–30% lower light intensity compared to no shade conditions. While the shade of papaya and plastic net 55% resulted in 37–43% and 52–61% lower light intensity than the treatment without shade. In addition to decreasing

Table 4. Microclimate in different type of shade

Microclimate	Type of Shade	Week After Planting			Average
		3	5	7	
Light Intensity (Lux)	No Shade	130400.86	122800.16	133400.96	1289.33
	Sweet Corn	127600.71	120000.77	93000.11	1135.86
	Papaya	74700.44	70900.30	83600.11	764.28
	Plastic Net 55%	51000.76	56300.11	63700.29	603.72
Temperature (^{o}C)	No Shade	31.88	30.30	32.50	31.56
	Sweet Corn	31.30	29.74	28.55	29.86
	Papaya	27.93	26.76	30.65	28.45
	Plastic Net 55%	29.87	28.41	30.69	29.66
Relative Humidity (%)	No Shade	84.84	82.48	78.09	81.80
	Sweet Corn	84.80	84.36	91.19	86.78
	Papaya	94.84	92.23	90.97	92.68
	Plastic Net 55%	85.92	85.53	89.09	86.85

light intensity, the presence of shade also reduced temperature and increased relative humidity. Papaya shade produced the lowest temperature, which is 26.76–30.65 °C and the highest humidity is 90.97–94.84% (Table 4).

3.2.2 Tomato Genotypes and Different Type of Shades Interaction on Tomato Crop Yield

The difference in microclimate between shade-type treatments led to differences in productivity between different tomato genotypes. Tomato genotype 4979 produced the highest fruit weight per plant in no shade, sweet corn, and papaya shade. Meanwhile, genotypes G370-1 and G384-11 produced the highest fruit weight per plant at 50% plastic net shade (Table 5). Baharuddin et al. [19] also reported the existence of genetic and environmental interactions between various tomato genotypes with various levels of plastic net shade.

Other observations showed that genotypes G384-11 and G326-4 were tomato genotypes that loved the shade of sweet corn because they produced higher productivity in sweet corn shade than in without shade. The tomato genotypes SSH and G380-13 were classified as tomato genotypes that loved papaya shade because they were able to produce higher productivity in papaya shade conditions than in no shade conditions. Meanwhile, tomato genotypes G370-1 and G384-11 were tomato genotypes that liked 50% plastic net shade because they produced higher productivity in 50% plastic net shaded conditions than those without. The presence of shade can increase the yield of tomato plants by increasing the fruit set and the number of fruit planted in the shade-loving tomato genotypes (Table 5).

Table 5. Tomato genotypes and different type of shades interaction on tomato crop yield

Genotypes	No Shade	Sweet Corn	Papaya	Plastic Net	Average
Palupi	285.04^{b}	186.76^{b}	211.66^{abc}	233.17^{ab}	229.16^{b}
G370-1	143.13^{c}	36.50^{c}	194.36^{bc}	311.82^{a}	171.45^{bc}
SSH3	190.75^{bc}	179.25^{b}	233.75^{ab}	235.57^{ab}	209.83^{bc}
G380-16	283.97^{bc}	259.75^{ab}	156.75^{bc}	259.20^{ab}	239.92^{b}
Karina	215.64^{bc}	154.68^{bc}	121.28^{bc}	137.16^{bc}	157.19^{c}
4979	488.92^{a}	373.68^{a}	350.09^{a}	258.52^{ab}	367.80^{a}
G384-11	192.83^{bc}	257.50^{ab}	186.92^{bc}	302.85^{a}	235.02^{b}
TORA IPB	251.16^{bc}	211.81^{b}	85.14^{c}	52.99^{c}	150.28^{c}
G380-13	193.08^{bc}	28.63^{c}	233.17^{ab}	236.57^{ab}	172.86^{bc}
G326-4	181.51^{bc}	258.98^{ab}	187.12^{bc}	253.26^{ab}	220.22^{bc}
Average	**242.60**	**194.75**	**196.02**	**228.11**	

Note: The same letter in the same column is not significantly different at the 5% level.

4 Conclusion

The response of tomato genotypes varies as a form of adaptation to shade. All tomato genotypes when shaded adapted by increasing plant height, number and leaf area, thinner of leaves, shorter palisade layers, maintaining stomata number and deeper harvesting time. The shade-loving tomato genotype had better adaptation tolerance than sensitive, in response to obtaining optimal solar radiation when shaded.

The characteristics of morphological, anatomical and phenological adaptations of shade-loving tomato plants on low light intensity, are taller plants, wider and thinner leaves, shorter palisade, and high stomata density. The adaptation character of this shade-loving genotype resulted in a better growth response, so that it could absorb higher light energy and increase tomato productivity.

The characters of leaf thickness, palisade height, harvest age, number of fruit and weight per fruit are characters that directly affect production per plant. These characters can be used for character selection, as an effort to produce high yielding tomatoes in planting under shade.

Genotypes 370-1 and 384-11 are genotypes that like 50% shade, have better production than commercial varieties. Genotypes 380-13, SSH3, and 4979 were shade-loving papaya genotypes, tomato genotypes 326-4, 380-16, and 381-11 were shade-loving maize genotypes; and has a production that tends to be better than commercial varieties.

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