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Estimation of genetic parameters and variability of various cayenne peppers under net shading

GRETTY FEBRIOLA SIAHAAN[1,♥], MUHAMMAD ACHMAD CHOZIN[2,♥♥], MUHAMAD SYUKUR[2], ARYA WIDURA RITONGA[2]

[1]Graduate Program of Agronomy and Horticulture, Department of Agronomy and Horticulture, Faculty of Agriculture, Institut Pertanian Bogor. Jl. Meranti, Kampus IPB Darmaga, Bogor 16680, West Java, Indonesia. Tel./fax.: +62-251-8629347, ♥email: adyah8570@gmail.com
[2]Department of Agronomy and Horticulture, Faculty of Agriculture, Institut Pertanian Bogor. Jl. Meranti, Kampus IPB Darmaga, Bogor 16680, West Java, Indonesia. Tel.: +62-251-8629354, Fax.: +62-251-8629352, ♥♥email: m_chozin@apps.ipb.ac.id

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Abstract. *Siahaan GF, Chozin MA, Syukur M, Ritonga AW. 2023. Estimation of genetic parameters and variability of various cayenne peppers under net shading. Biodiversitas 24: 5912-5919.* The intercropping systems are important concerning the decreasing agricultural land and the increasing population. Chili could be planted as intercrops, but not all chili genotypes were adapted to low light-intensity stress. This study aims to determine the genetic diversity of cayenne pepper under 50% plastic net shade conditions based on morphological and agronomic traits. The study was conducted at the Cikabayan Experimental Field, Institut Pertanian Bogor, Dramaga, Bogor, from January to July 2021. The genetic material consisted of ten genotypes of cayenne pepper from *Capsicum annuum* L. and ten from *Capsicum frustescens* L.. Each genotype of chili was planted with three replications, so there were 60 experimental units. Each experimental unit consisted of six plants planted in an area of 1.5 m^2. The shade used was a plastic net shade with a 50% shading level. The estimation of genetic parameters showed that leaf area, number of leaves, fruit weight, number of fruits, and yield per plant had a high genotypic coefficient of variation (GCV) and broad-sense heritability (Hbs). Cluster analysis resulted in two main clusters based on twelve chili growth and agronomic characters. All chili genotypes included in Cluster 1 were *C. annuum* chilies. On the other hand, all the chili genotypes in Cluster 2 were *C. frutescens* chilies except for the G19 genotype. Cayenne pepper in Cluster 2 had a higher number of leaves, plant height, stem diameter, leaf area, fruit diameter, pedicle length, fruit weight, number of fruits, and yield per plant than cayenne pepper in Cluster 1. The result of this study indicates that *C. frutescens* cayenne pepper has more potential to be planted under shading conditions and used in intercropping than *C. annuum*.

Keywords: *Capsicum annuum*, *Capsicum frutescens*, intercropping, low light stress, PCA

INTRODUCTION

Increasing land effectiveness is important to do in the face of decreasing agricultural land and increasing population. Agricultural land for cereals and vegetable commodities continues to decrease from 2017 to 2019 in Indonesia and Southeast Asia (FAO 2021). The increase in the world population reached 758 million (11%) from 2009 to 2018 (FAO 2021). Polyculture systems such as agroforestry and intercropping can be used to increase the effectiveness of agricultural land (Chapagain and Riseman 2014; Zohry et al. 2017; Arsyad et al. 2020).

Intercropping is a polyculture method involving two or more types of plants in one planting area simultaneously. The land under shading of horticultural crops, plantation crops, forestry plants, and other crops has the potential to be developed for polyculture systems. The potential area of land under the auspices of plantation crops in Indonesia in 2016 reached more than 21 million ha, while the potential area under production forest land in 2012 reached more than 15 million ha (Ministry of Agriculture Republic of Indonesia 2021). This was combined with the area of land within yards. However, land under other crops tends to have a limited growing environment. The sunlight that intercrops can access tends to be limited so, there is low light-intensity stress on land under shade. Low light stress leads to declines in photosynthesis rate (Blomme et al. 2020), carbohydrate synthesis, and productivity of the plants (Ritonga et al. 2018). Polthanee et al. (2011) reported a decrease in soybean yields ranging from 3.70 to 30.95% at 70% shade. Dutta et al. (2017) also reported decreased rice yields ranging from 50 to 80% under 70% shade conditions. The development of plant varieties adapted to low-light-intensity stress is needed to support the polyculture system.

Chili pepper (*Capsicum* spp.), especially cayenne pepper, is one of the most important vegetables in Indonesia, with the largest harvested area compared to other vegetables (Ministry of Agriculture Republic of Indonesia 2021). Chilies and onions are often the main contributors to rising inflation in the volatile foods category in Indonesia (Bank Indonesia 2021). In addition, chili was a potential crop to be planted beneath stands and developed in polyculture systems: *Capsicum* and other Solanaceae family, including the nightshade plant (Tezcan et al. 2019). Shade at a certain level can increase the growth and productivity of nightshade plants (Jeeatid et al. 2017). The green (fresh) chili yield significantly increased under 35% shading intensity but significantly decreased when planted in up to 75% shading conditions (Andhale et al. 2014).

The development of shade-tolerant plants has been undertaken for various other commodities. Sulistyowati et al. (2016) reported that tomato genotypes were tolerant (shade-loving and shade-tolerant) until 50% shading intensity. Using shade-loving tomato genotypes under 50% shading conditions could increase the productivity of tomatoes by up to 30% (Sulistyowati et al. 2016). The productivity of adaptive rice genotypes under low-light stress (70% shading) was equal to or higher than rice productivity under optimum conditions (Dutta et al. 2017).

On the other hand, many challenges are faced in developing chili as an intercrop. Not all chili genotypes were adapted to low light-intensity stress. The difference in light intensity was one of the causes of the genotype x environment interaction on chili productivity (Jeeatid et al. 2018). This causes the importance of evaluating the genetic diversity of chili peppers under low-light stress to support the improvement of low-light adaptive chili varieties. This study aims to determine the genetic diversity of cayenne pepper under 50% plastic net shade conditions based on morphological and agronomic characteristics.

MATERIALS AND METHODS

Study area and genetic material

The study was conducted at the Cikabayan Field, Institut Pertanian Bogor Experimental Research, Dramaga, Bogor, West Java, from January to July 2021. The genetic material consisted of 10 genotypes of cayenne pepper from *Capsicum annuum* L. and 10 from *Capsicum frutescens* L. (Table 1). Each genotype of chili was planted with 3 replications, so there were 30 experimental units. Each experimental unit consisted of 6 plants planted in an area of 1.5 m^2. The shade used was a plastic net shade with a 50% shading level.

Table 1. The genetic material of 20 chili peppers

No	Genotype	Species
G1	F10.145291-10-7-1-1-1-2-3-6	*C. annuum*
G2	F10.145291-115-8-1-1-1-4k	*C. annuum*
G3	F10.160291-3-12-5-51-1-1-2-2-1	*C. annuum*
G4	F8.145291-14-9-3-12-1	*C. annuum*
G5	F10.145174-9-7-1-5-3-1-2-5	*C. annuum*
G6	Harita	*C. annuum*
G7	Genie	*C. annuum*
G8	Bara	*C. annuum*
G9	Pelita F1	*C. annuum*
G10	Lentera	*C. annuum*
G11	F9.285290-6-10-1-1-1-1B	*C. frutescens*
G12	F8.285290-290-2-1-2-1	*C. frutescens*
G13	F8.285290-290-9-1-4-2-1	*C. frutescens*
G14	F8.285290-50-8-1-1-4-8	*C. frutescens*
G15	F8.285290-123-6-15-4-1-1	*C. frutescens*
G16	F7.321290-5-2-2-1-4B	*C. frutescens*
G17	F9.321290-252-10-8-3(1)-B	*C. frutescens*
G18	Bonita	*C. frutescens*
G19	Cakra Putih	*C. frutescens*
G20	Pulaipila Putih	*C. frutescens*

Procedures

The study began with the nursery, which was carried out on a plastic seedling tray. The seedling media used consisted of a mixture of soil:compost:husk charcoal (1:1:1). Chili seeds were sown 1 seed per seedling hole. The nursery tray was placed in the nursery greenhouse. Watering was done 2 times a day in the morning and evening. The NPK 16:16:16 fertilizer was given when the nursery was 2 weeks after sowing with a concentration of 2 g/l and a fertilization volume of 500 mL per nursery tray. Along with the nursery, land preparation was also conducted. Land preparation consisted of applying 10 tons of manure and 2 tons of dolomite per ha, making beds 1 m wide and 20 cm high, and installing plastic mulch and plastic net with 50% shade intensity on the planting beds.

Chili plants were transferred to the beds after 4 weeks of sowing. Planting was done with a randomized complete block design (RCBD) with 3 replications. Chili plants were planted on planting beds with a spacing of 50 × 50 cm. A bamboo stake measuring 1.2 m was used to support the growth of each plant. The NPK fertilizer with a 5-15 g/L concentration was given to plants according to the plant growth phase. Fertilization was done by giving 250 mL of fertilizer solution in the planting hole for each fertilization application. Insecticides, fungicides, bactericides, and acaricides were applied weekly with recommended doses.

Observations were made on the growth traits, yield components, and plant productivity. Growth traits comprised greenish leaves, the number of stomata, plant height, stem diameter, leaf area, and the number of leaves per plant observed 12 weeks after planting. The greenness of the leaves was observed using a SPAD meter. The leaves used for observation are those between the 3^{rd} and 4^{th} nodes after dichotomous. The yield component traits observed consisted of fruit diameter, fruit length, fruit pedicle length, and weight per fruit. The fruit used for observation was the fruit that comes from the 3^{rd} node after the dichotomous. The yields observed in this study were the number of fruit characteristics and fruit weight per plant. Yield characteristics were calculated from the first harvest to the last harvest.

Observations of the microclimate were also carried out in this study. The observed micro-climates were light intensity, temperature, and relative humidity. Light intensity was measured using a digital mini lux meter UT383. Temperature and relative humidity were measured using a USB 2.0 Data Logger for humidity and temperature. Microclimate observations were carried out in the morning (at 08.00 AM), afternoon (at 01.00 PM), and evening (at 4.00 PM) once every three days during the study.

Data analysis

Data were subjected to Analysis of Variance (ANOVA) using the PKBT Stat 3.1(http://pbstat.com/pkbt-stat/). The ANOVA for all traits was carried out separately and presented in Table 2. The Mean value, range, and coefficient of variance are presented in Table 3. Heritability was estimated as per the procedure presented by Burton and DeVane (1953), Johnson et al. (1955), and Hanson et al. (1956). Hierarchical Cluster Analysis (HCA) was conducted to study the similarities and dissimilarities of 20 chili genotypes using Microsoft Excel and Minitab 16. Principal Component Analysis (PCA) was implemented to summarize and describe the inherent genetic variation in chili genotypes by Star software by International Rice Research Institute (IRRI) (http://bbi.irri.org/products). A two-sample t-test was applied to find the significance level between the clusters for twelve quantitative traits.

RESULTS AND DISCUSSION

Microclimate under 50% shade net

The results of the microclimate observations are presented in Figure 1. The average light intensity per day ranged from 22,586-49,907 lux, with average temperatures ranging from 28-34°C and relative humidity from 54-68%. The microclimate during the study was classified as less than optimum to optimum for chili cultivation. The optimum light intensity in chili ranged from 35,000-50,000 lux with a daytime temperature of 30-33°C on the *C. annuum* (Samanta and Hazra 2019). Low light intensity stress on tomatoes (including nightshade plants) occurs at the lux light intensity of 32,000 (Sulistyowati et al. 2016). Chilies were more resistant to full sunlight than tomatoes (Masabni et al. 2016), indicating that the light intensity of 32,000 lux can also be a stress for chili. Rajasekar et al. (2013) also reported that the light intensity of 25,867 lux was a stress for chili production.

Under shading conditions, microclimatic conditions change significantly. The intensity of light decreases as the level of shade increases, thereby reducing the value of photosynthetic active radiation (PAR) in a way that can potentially disrupt plant growth. However, at certain levels, shaded conditions can positively affect plant growth and increase productivity. According to Wang et al. (2022), intercropping can reduce light intensity by 10% to 80%. On the other hand, chili plants can still thrive and produce better yields under 35% shading conditions (Pouliot et al. 2012).

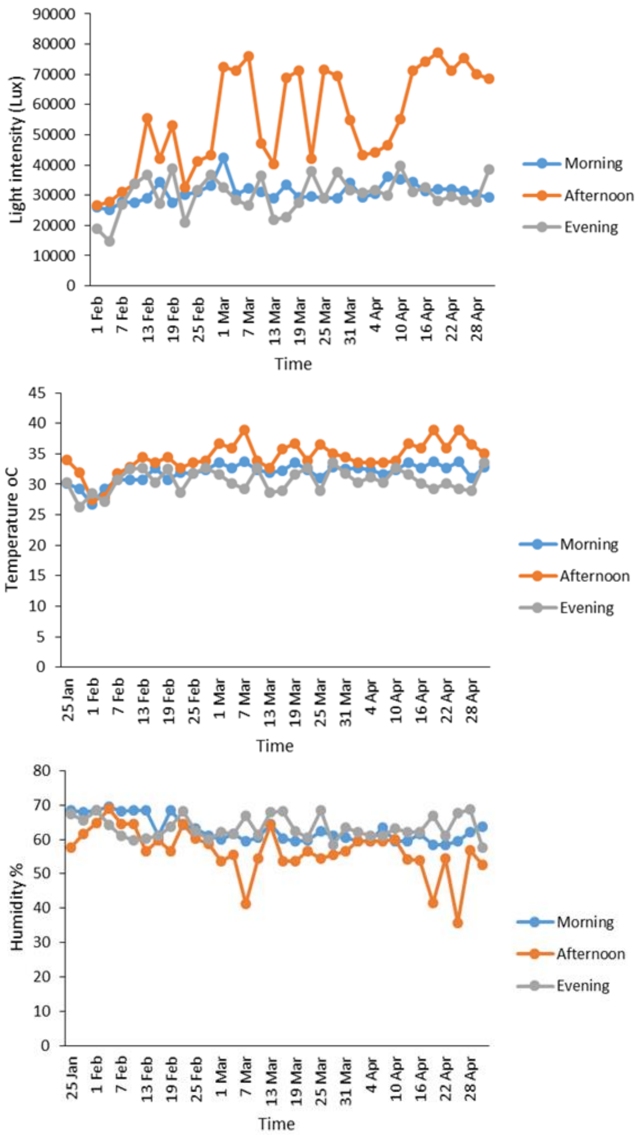

Figure 1. Light intensity, temperature, and humidity at the location during the study

Table 2. Analysis of variance (mean square) for twelve quantitative traits in pepper

Characteristics	Mean square			CV (%)
	Replication	Genotype	Error	
SPAD value	45.21*	24.82*	11.06	5.91
Number of stomata	2,611.33^{ns}	3,652.44**	1,057.24	11.46
Plant height (cm)	5,278.27**	1,177.43**	123.3	10.35
Stem Diameter (mm)	23.49**	5.38**	1.17	11.18
Leaf area (cm^2)	575.77^{ns}	5,562.37**	436.6	24.3
Number of leaves	6,365.10^{ns}	15,157.07**	3,190.76	28.63
Fruit diameter (mm)	0.05^{ns}	8.01**	0.1	3.54
Fruit length (cm)	0.16^{ns}	1.25**	0.07	6.07
Pedicle length (cm)	0.08^{ns}	0.94**	0.05	6.51
Fruit weight (g)	0.00^{ns}	1.15**	0.01	6.61
Number of fruits	246.92*	1,460.44**	72.38	9.85
Yield per plant (g)	511.96^{ns}	13,039.08**	175.02	11.02

Notes: CV: coefficient of variance; *: significant at level of 5%; **: significant at level of 1%; ns : not significant

Table 3. Estimated genotypic and phenotypic coefficient of variation of chili pepper under 50% shading condition

Characteristics	Range	Mean	S.E.	GCV	Category	PCV	Category	Hbs	Category
SPAD value	50.53-63.30	56.26	0.14	3.81	Low	7.03	Low	29.31	Moderate
Number of stomata	227.89-338.44	283.84	1.74	10.36	Moderate	15.45	Moderate	45.00	Moderate
Plant height (cm)	77.44-138.33	107.30	0.99	17.47	Moderate	20.30	High	74.02	High
Stem Diameter (mm)	7.49-11.63	9.65	0.07	12.27	Moderate	16.62	Moderate	54.53	High
Leaf area (cm^2)	37.26-165.70	86.00	2.15	48.07	High	53.86	High	79.65	High
Number of leaves	113.11-364.11	197.31	3.55	32.01	High	42.94	High	55.56	High
Fruit diameter (mm)	7.10-12.43	9.00	0.08	18.03	Moderate	18.37	Moderate	96.35	High
Fruit length (cm)	3.37-5.37	4.22	0.03	14.88	Moderate	16.15	Moderate	84.89	High
Pedicle length (cm)	2.47-4.53	3.39	0.03	16.06	Moderate	17.36	Moderate	85.58	High
Fruit weight (g)	0.80-3.10	1.54	0.03	39.96	High	40.48	High	97.44	High
Number of fruits	57.00-137.53	86.34	1.10	24.91	High	26.79	High	86.47	High
Yield per plant (g)	46.93-303.37	120.04	3.30	54.55	High	55.66	High	96.08	High

Notes: S.E.: standard error; GCV: genotypic coefficient of variance; PCV: phenotypic coefficient of variance; Hbs: broad sense heritability

Plant genetic variability under shading conditions

Analysis of variance showed that there was a significant effect of chili genotype on all chili traits observed (Table 2). This was an early indication of the genetic diversity of chili plants when grown under 50% plastic net shade (low light intensity stress). Variance due to genotypes was highly significant for all the characters studied, indicating that the genotypes selected were genetically different (Saravanan et al. 2019). Genetic diversity is crucial in producing cayenne pepper varieties adaptive to low light-intensity stress. Genetic diversity was the main asset in plant breeding (Singh et al. 2015); the higher genetic diversity, the greater the opportunity for plant improvement according to the desired idiotype. This variation provides ample scope for the plant breeder to select superior genotypes for crop improvement (Sujatha and Pushpavalli 2017).

Estimation of genetic parameters was carried out to confirm the existence of genetic variability among chili genotypes under 50% net plastic shade conditions. High broad-sense heritability (Hbs) and genotypic coefficient of variation (GCV) indicate a high genetic influence on phenotypic variability. The results of the estimation of genetic parameters showed that the character of leaf area (48.07), number of leaves (32.01), fruit weight (39.96), number of fruits (26.79), and yield per plant (54.55) have high GCV. These characters also have a high broad sense heritability. This indicated that genetic factors influenced the variability in these characters more than environmental factors under the plastic net shade with a 50% shading level. On the other hand, characters number of stomata (10.36), plant height (17.47), stem diameter (12.27), fruit diameter (18.03), fruit length (14.88) and pedicle length (16.06) have a moderate GCV category, while the SPAD value is in the low category (Table 3). According to Terfa and Gurmu (2020), GCV and PCV values are grouped into three categories: low (<10%), moderate (10-20%), and high (>20%).

In line with the result of this experiment, genotypic coefficient of variation (GCV) and broad-sense heritability (Hbs) in chili have been widely reported. There was a high GCV and Hbs (68-99%) on the characteristics of fruit length, fruit diameter, fruit weight and number of fruits per plant in *C. annuum* under optimum conditions (Jogi et al. 2017; Nahak et al. 2018; Sindhusha and Rawat 2020). However, the values of GCV and Hbs on cayenne pepper have not been widely reported, especially in conditions of low light-intensity stress. The high GCV and Hbs (75-96%) were found in the characters of fruit length, fruit diameter, and yield per plant in the cayenne pepper plant at optimum conditions (Vaishnavi et al. 2018). This research provides new information regarding the GCV, PCV, and Hbs values of cayenne pepper's morphological and physiological characteristics under shade conditions.

In this study, moderate to high GCV values can indicate that genetic factors significantly influence the observed traits in shade conditions. On the other hand, it is also known that the difference in values between PCV and GCV for each trait is low. This result suggests that environmental factors have a relatively minor impact on the observed traits.

The results also indicate that the observed traits exhibit high broad-sense heritability, except for the SPAD value and the number of stomata. Heritability values show the extent of genetic influence on a trait. This conclusion aligns with the earlier discussion, where the low GCV of the SPAD value suggests that genetic factors have less influence on the variation in SPAD value and are more influenced by environmental factors. The high GCV and Hbs values in most of the characters in this study were thought to be due to the different responses of different chili genotypes to low light-intensity stress. There was a decrease in the fruit number and fruit weight per plant under shading conditions by 24% and 50% (Rajasekar et al. 2013; Masabni et al. 2016). However, Díaz-Pérez (2013) reported increased chili yield by 30-47% when shaded. This indicates that the chili genotype used by Díaz-Pérez (2013) is more tolerant to low light-intensity stress than the chili genotype by Rajasekar et al. (2013) and Masabni et al. (2016) studies. In tomatoes, Sulistyowati et al. (2016) reported that there were four types of tomatoes based on their response to low light intensity stress (50% net shade), namely shade-loving, shade-tolerant, moderate shade-tolerant, and shade-sensitive tomatoes. On the other hand, chili tends to be very sensitive to shading conditions. According to Blomme et al. (2020), chili plants planted under the stands of other plants can experience a reduction in biomass of up to more than 90%, depending on plant density. The presence of two chili species (*C. annuum* and *C. frutescens*) used in this study was also thought to cause the high GCV and Hbs values even though both were classified as cayenne pepper.

High GCV and Hbs values increase the chances of obtaining cayenne pepper varieties more adaptive to low light-intensity stress. Genetic divergence effectively chooses parents for hybridization and breeding programs (Karuppaiyan et al. 2013; Mazid et al. 2013). The adaptive cayenne pepper to low light intensity stress can be obtained by recombining between genotypes with a high leaf area, number of leaves, fruit weight, number of fruits, and yield per plant. A positive and significant correlation existed between fruit weight and the number of fruits on yield per plant in pepper (Iwo et al. 2016; Esho 2019). Samanta and Hazra (2019) reported a significant and positive correlation between fruit weight and the number of fruits on yield per plant in sweet peppers both in open fields and under shading nets. Ritonga et al. (2018) reported a significant and positive correlation between fruit weight and fruit number per plant on yield in tomatoes under 50% plastic net shading condition. Sulistyowati et al. (2016) also reported an increase in the number of leaves per plant and fruit weight per plant in the shade-tolerant and shade-loving tomato genotypes under plastic net shade with a 50% shade intensity.

The high GCV and Hbs values for yield characters also indicated that the selection of cayenne genotypes that were adaptive/tolerant to stress of low light intensity was effectively carried out in 50% plastic net shade. Plastic shade that is too low in shade level does not become a stress for chili plants, while plastic net shade that is too high causes low production of all chili genotypes. Samanta and Hazra (2019) reported that all chili genotypes experienced a decrease in production when shaded <35,000 lux (75% shade level). Sulistyowati et al. (2016) reported that a plastic net of 50% shading condition was the best selection environment for selecting shade-tolerant genotypes in tomatoes.

The cluster analysis resulted in two main clusters based on 12 chili growth and agronomic characters. All genotypes in Cluster 1 were *C. annuum* chilies. On the other hand, all the genotypes in Cluster 2 were *C. frutescens* chilies except for the G19 genotype. This result indicates that the grouping between chili genotypes at low light intensity stress is more due to differences in response between chili species even though the two species used are the same as cayenne pepper.

The coefficient of similarity between the two main clusters is 0.26 (dissimilarity: 0.74), which is lower than the lowest similarity coefficient in Clusters 1 (similarity: 0.50; dissimilarity: 0.50) and Cluster 2 (similarity: 0.39; dissimilarity: 0.61). This indicates a high diversity among *C. annuum* and *C. frustescens* species and within *C. annuum* and *C. frustescens* during low light intensity stress. These results are in line with the research conducted by Carvalho et al. (2014) that the dissimilarity coefficient (0.75) of various chili genotypes (involving *C. frustescens* and *C. chinense*) was higher than the dissimilarity coefficient of various chili genotypes (0.45) reported by Orobiyi et al. (2017) which only involved *C. annuum.*

The result of the clustering analysis showed differences in plant performance when grown under shading conditions. The blue color on the heatmap indicates that the observed variable has a high value, whereas the red color indicates a lower value. Heatmap analysis shows that genotypes belonging to Cluster 1 have shorter plant sizes (plant height: 91.13 cm) and lower production (yield per plant: 72.96 g) (shown on the heatmap in blue color). In contrast, the genotypes belonging to Cluster 2 were characterized by better morphological performance (plant height: 127.07 cm) and higher production (yield per plant: 177.57 g) under 50% shading conditions (shown on the heatmap in red color). The difference between cluster also shown in Table 5.

Principal Component Analysis

This study carried out principal component analysis (PCA) to observe each character's effect on the diversity between genotypes. From the analysis results, it is known that 3 main components have an eigenvalue above 1.0. The 3 main components were able to explain the diversity between genotypes by 77.00% (Table 4). PC1, with an eigenvalue of 6.41, contributed 53.42%, the PC2, with an eigenvalue of 1.64, contributed 13.66% (Figure 3), and the PC3, with an eigenvalue of 1.21, contributed 10.05% to the total diversity among the 20 test genotypes. The large cumulative variance of the 3 main components indicates that the traits between them greatly influenced the phenotype, so they can be used for selection among test genotypes (Rosmaina et al. 2022).

On PC1, the characters of plant height (-0.369), stem diameter (-0.346), fruit weight (-0.348), and yield per plant (-0.350) had the highest contribution to total diversity. In PC2, the characters with the highest contribution are the number of leaves (-0.426), fruit length (-0.436), and number of fruits (0.389), while in PC3, the characters with the highest contribution are the number of stomata (0.676). From the results of the PCA, the number of stomata, fruit length, and number of fruits are offered as the main characters that can be used as chili plant selection traits under 50% shade conditions. These traits have a high contribution, observed in the first three principal components. This shows that the total diversity among genotypes is largely due to the diversity of these characters.

Table 4. Principle component analysis (PCA) for twelve quantitative traits in chili peppers under 50% shade conditions

Traits	PC1	PC2	PC3
SPAD value	0.058	0.369	-0.040
Number of stomata	0.099	0.375	0.676
Plant height	-0.369	0.149	0.087
Stem diameter	-0.346	0.045	0.096
Leaf area	-0.328	0.069	0.339
Number of leaves	0.240	-0.426	-0.105
Fruit diameter	-0.334	0.070	-0.344
Fruit length	-0.237	-0.436	0.217
Pedicle length	-0.299	-0.287	0.305
Fruit weight	-0.348	-0.270	-0.016
Number of fruits	-0.254	0.398	-0.266
Yield per plant	-0.350	0.062	-0.262
Standard deviation	2.532	1.280	1.098
Proportion of variance	0.534	0.137	0.101
Cumulative proportion	0.534	0.671	0.771
Eigenvalues	6.410	1.639	1.206

On the other hand, the results of the GT biplot analysis showed a grouping of the test genotypes. It was observed that two clusters were formed. From the GT biplot analysis, it was known that G13 and G18 were in the extreme regions of the graph and were superior genotypes. Both genotypes are strong plants with good performance and high production under 50% shaded conditions.

The cluster difference was studied using a two-sample t-test for 12 quantitative traits. Character differences were observed in 10 of the 12 characters tested (Table 5). In general, the plants in Cluster 2 had better plant performance than those in Cluster 1. The genotypes belonging to Cluster 1 have a greater number of leaves than those in Cluster 2. In contrast, genotypes originating from *C. frutescens* (Cluster 2) were observed to have better plant height, stem diameter, leaf area, fruit character, and productivity.

Figure 2 and Figure 3 show that twenty genotypes of cayenne pepper are grouped based on different species. Cluster 1 consists of genotypes from the species *C. annuum*, while Cluster 2 consists of genotypes derived from *C. frutescens*. Based on the results of this study, genotypes derived from *C. frutescens* species had better performance and yields under shaded conditions than genotypes derived from *C. annuum*.

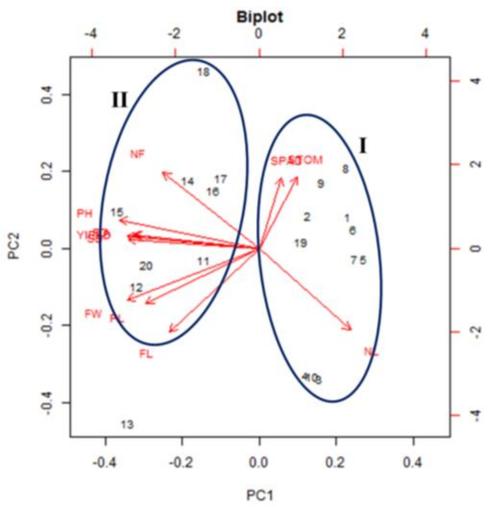

Figure 3. Genotypes by trait biplot illustrating the relationship between PC1 and PC2 for 20 genotypes and twelve traits of pepper

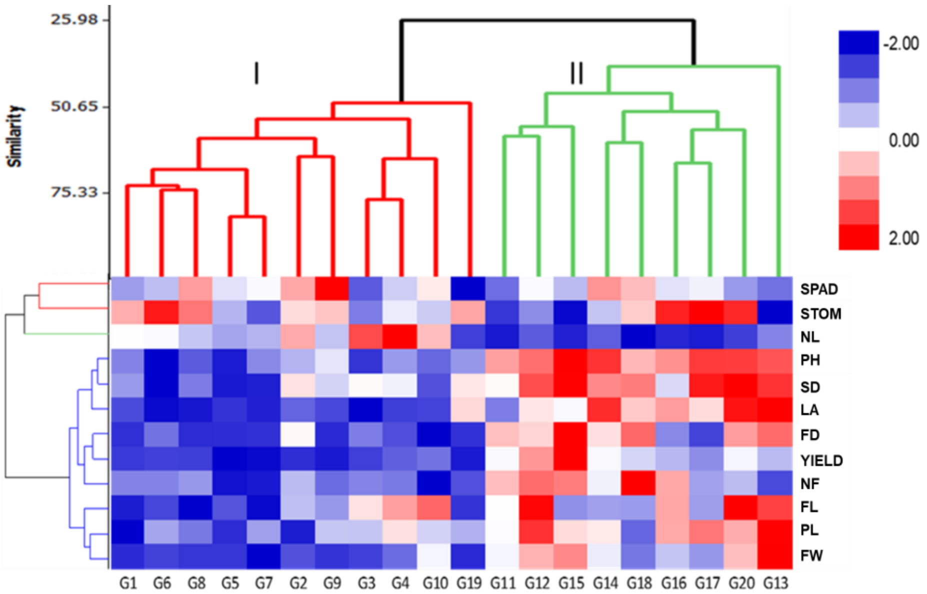

Figure 2. Cluster heatmap of pepper genotypes. The dendrograms are based on the Euclidean linkage algorithm. G1-G2: genotypes used including *C. annuum* (G1-G10) and *C. frutescens* (G11-20) species; SPAD: SPAD value; STOM: number of stomata; PH: plant height; SD: stem diameter; LA: leaf area; NL: number of leaves; FL: fruit length; FD: fruit diameter; PL: pedicle length; FW: fruit weight; NF: number of fruits; YIELD: yield per plant

Table 5. Cluster mean for twelve quantitative traits in pepper

Characters	Cluster 1	Cluster 2	p-value	Characters	Cluster 1	Cluster 2	p-value
SPAD value	56.46	56.01		Fruit diameter (mm)	7.91	10.34	**
Number of stomata	286.95	280.05		Yield per plant (g)	72.96	177.57	**
Number of leaves	243.71	140.60	**	Number of fruits	72.64	103.09	**
Plant height (cm)	91.13	127.07	**	Fruit length (cm)	3.95	4.54	*
Stem diameter (mm)	8.74	10.77	**	Pedicle length (cm)	3.05	3.80	**
Leaf area (cm^2)	55.33	123.47	**	Fruit weight (g)	1.13	2.04	**

Notes: *: significantly different based on a two-sample t-test at the level of 5%; **: significantly different based on a two-sample t-test at the level of 1%

Sun et al. (2021) state that plant response to suboptimal conditions varies between genotypes. This diversity was widely observed in morphological characteristics such as plant height, number of leaves, and yield component. In addition, there are other indicators, such as stomata character and photosynthesis. The results obtained in this study support and are in line with other studies that have been previously reported.

Planting in the shade tends to cause suboptimal conditions, especially in low light intensity. Plant tolerance to stress caused by low light conditions depends on the specific genotype used. As noted by Pouliot et al. (2012), chili plants can survive in shaded conditions and have better productivity, so improvements in tolerance to shade can be sought. The improvement can be achieved through several characteristics, such as increased photosynthetic efficiency and other related features. This study showed a performance difference between cayenne peppers of the *C. annuum* species and those of the *C. frutescens* species. The better performance of *C. frutescens* species can be attributed to a good adaptation to shade conditions. As a result, genotypes derived from the *C. frutescens* species are better suited for planting as intercrops than *C. annuum*.

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