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Variability of yield and yield components of 23 hybrid cayenne pepper (*Capsicum frutescens*) genotypes under shaded and unshaded conditions

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Abstract. *Putri DRM, Syukur M, Ritonga AW. 2025. Variability of yield and yield components of 23 hybrid cayenne pepper (*Capsicum frutescens*) genotypes under shaded and unshaded conditions. Biodiversitas 26: 396-406.* Cayenne pepper production is challenged by limited agricultural land, necessitating a sustainable intercropping system to meet rising demand. This requires varieties that can grow, develop, and produce under shade-stress conditions. This study aimed to obtain information on the variability of growth, yield components, and physiological traits and to determine yield-related traits in cayenne pepper hybrids obtained from full-diallel crosses under shaded and unshaded conditions. A total of 23 genotypes, consisting of 20 F1 hybrids from five parental lines and three comparisons, were planted using a nested randomized complete block design with two factors: shade and genotype. The results showed that G8 and G27 exhibited superior performance under shade conditions, producing a higher number of fruits per plant, fruit yield per plant, marketable number of fruits, marketable yield fruit, fruit diameter, and fruit weight compared to unshaded conditions. These findings have practical implications for cayenne pepper production, as they can guide the selection of varieties for shaded conditions. Chili was categorized into six clusters under unshaded conditions and four clusters under shaded conditions. Marketable yield fruit, marketable number of fruits, and number of fruits per plant had a significant positive correlation coefficient on fruit yield per plant under unshaded conditions. In contrast, under shaded conditions, there was a significant positive correlation shown on fruit diameter, plant height, marketable yield fruit, number of fruits per plant, marketable number of fruits, and fruit weight.

Keywords: Cayenne pepper hybrid, full-diallel, shade stress, tolerant genotype, yield

INTRODUCTION

Cayenne pepper (*Capsicum frutescens* L.) is a horticultural commodity with high economic value and is widely cultivated by farmers in both the highlands and lowlands regions. Chili peppers contain capsaicin compounds that control the spiciness of chili fruit (Yang et al. 2020; Xiang et al. 2021). The demand for chili peppers continues to increase annually, correlating with population growth and expansion in the food and pharmaceutical industries. Efforts to enhance the production of cayenne pepper face various challenges, including the decreasing area of agricultural land and the limited land ownership among farmers in Indonesia.

According to FAO (2024) data, the global agricultural land area decreased by 0.126% between 2021 and 2022. The global chili harvest area also decreased by 33,056 ha over three years (2020-2022). The Ministry of Agriculture Republic of Indonesia (2022) reported a 1.78% decrease in farm size between 2015 and 2019. BPS (2023) showed that the harvest area of chili fluctuated between 2018 and 2022. Furthermore, limited land ownership among farmers presents a challenge in increasing cayenne pepper production. According to BPS (2018), approximately 58% of farming households control less than 0.5 ha of land, which has implications for the necessity to enhance the efficiency of agricultural land use. This study is crucial in addressing these challenges.

Agroforestry systems and intercropping of forestry, plantations, and yard crops present a potential to increase land use efficiency in Indonesia. However, low light-intensity stress (shading) in these cultivation systems can disrupt plant metabolic processes, resulting in decreased rates of photosynthesis and carbohydrate synthesis, ultimately leading to reduced plant productivity (Díaz-Pérez 2013; Laanisto and Niinemets 2015; Ritonga et al. 2018). The morphological characteristics, yield, and phenotype of plants are generally influenced by light intensity or shading conditions (Xu et al. 2016; Castronuovo et al. 2019; Setiawan et al. 2021). Species and varieties of crops give different responses to the shading related to their growth and development (Díaz-Pérez 2013). The development of plants with enhanced low-light tolerance is crucial for the utilization of shaded land, necessitating the cultivation of varieties that exhibit optimal growth and performance under shade-stress conditions (Dewi et al. 2022). Improving plant adaptation mitigates heat stress, optimizes light utilization, and enables crops to thrive in low-light or high-temperature environments (Benitez-Alfonso et al. 2023).

Chili (*Capsicum* spp.), especially cayenne pepper, is a C3 plant capable of growth in low light conditions. C3 plants maintain relatively efficient photosynthesis under low light conditions, as their Calvin cycle-based pathway allows for effective CO_2 fixation even when light intensity is limited, in contrast to C4 plants that are less adaptable to such conditions (Kubásek et al. 2013). Previous research has identified several genotypes of cayenne pepper that exhibit shade-tolerant and shade-loving; according to research by Siahaan et al. (2022), *C. frutescens* genotypes can maintain high yields under 50% shade conditions. Under shade conditions, the production of shade-loving genotypes increased. Conversely, the production of shade-sensitive and moderate genotypes decreased, while shade-tolerant genotypes demonstrated production levels that were not significantly different from unshaded conditions. However, there was an absence of low-light tolerant varieties of chilies with high yield potential in Indonesia. The effect of shade above 50% will generally give a negative growth response in the production of chili (Masabni et al. 2016), tomato (Sulistyowati et al. 2016; Rao et al. 2023), rice (Dutta et al. 2017), soybean (Tibolla et al. 2019), and corn (Gao et al. 2017; Susanti et al. 2023).

A potential solution to this issue is the development of high-yielding shade-tolerant hybrid cayenne pepper varieties. These hybrids necessitate evaluation under shaded conditions to ascertain their tolerance and adaptation to shade stress. Furthermore, it can identify which varieties exhibit optimal performance in terms of growth, yield, and quality. This study aimed to obtain information on the variability of growth, yield components, and physiological traits and to determine yield-related traits in cayenne pepper hybrids obtained from full-diallel crosses under shaded and unshaded conditions.

MATERIALS AND METHODS

Study area and material genetic

This study was conducted from January to July 2024. The experiment was conducted under shaded and unshaded conditions at the Pasir Kuda Experimental Farm of Institut Pertanian Bogor, Ciomas, Bogor, Indonesia (with an altitude masl 6°36'36.4" S; 106°47'04.1" E). The genetic materials used were 23 hybrid cayenne genotypes consisting of 20 F1 hybrids obtained from full diallel crosses of five parents (IPB C373, IPB C420, IPB C421, IPB C423, and IPB C424) and three comparisons (Rawita F1, F1.373340, and F1.373372). Information on the genetic material is presented in Table 1. The research design used was a nested randomized complete block design with two factors. The first factor in the main plot was shade, consisting of 0% shade and 50% shade. The second factor as a subplot is the genotype consisting of 20 F1 hybrids resulting from crossing five parents and three comparisons. There were 46 treatment combinations with three replications, resulting in 138 experimental units. Each experimental unit consisted of 12 plants, with five randomly selected sample plants.

Procedures

The study was initiated by hybridizing five parent plants in the IPB Alam Sinar Sari Residence greenhouse to create 20 cross combinations. The resulting seeds were then planted simultaneously at the Pasir Kuda Experimental Farm of Institut Pertanian Bogor, Bogor, Indonesia, using a plastic seedling tray with a soil:compost:husk charcoal medium (1:1:1). Chili seeds were sown at 1-2 seeds per hole. The trays were kept in a greenhouse and watered daily in the morning. Land preparation, conducted two weeks prior to planting, included soil plowing, harrowing, bed formation, manure application, fertilization, and installing plastic mulch and a 50% shade net. Each bed received 20 kg of cow manure and 0.5 kg of agricultural lime. Basic fertilizers applied one week before planting included urea (200 kg ha^{-1}), SP-36 (150 kg ha^{-1}), and KCl (150 kg ha^{-1}). Mulch was laid on each 3x1 m bed.

The shading structure was built using shade nets with 0% and 50% densities on all frame sides, constructed two weeks before planting. The bamboo frame, oriented east to west, measured approximately 3 meters in height. At 5 weeks old, when plants had five leaves, the plant was transferred to planting beds with a spacing of 0.5×0.5 m; a bamboo stake supported each plant. ABMix liquid fertilizer (5 mL l^{-1}) was applied thrice weekly, with 250 mL of solution per plant per application. Weekly, insecticides, bactericides, acaricides, and fungicides were administered at recommended doses. Harvesting was done manually in stages over six weeks when 80% of chili fruits were red.

Table 1. Genetic material consisted of 23 genotypes of cayenne pepper

Code	Genotype	Source	No	Code	Genotype	Source
G7	IPB373 × IPB424	Hybrid	13	G22	IPB423 × IPB373	Hybrid
G8	IPB373 × IPB420	Hybrid	14	G23	IPB423 × IPB424	Hybrid
G9	IPB373 × IPB423	Hybrid	15	G24	IPB423 × IPB421	Hybrid
G10	IPB373 × IPB421	Hybrid	16	G26	IPB423 × IPB420	Hybrid
G12	IPB424 × IPB420	Hybrid	17	G27	IPB420 × IPB423	Hybrid
G13	IPB424 × IPB423	Hybrid	18	G28	IPB420 × IPB421	Hybrid
G14	IPB424 × IPB421	Hybrid	19	G29	IPB420 × IPB424	Hybrid
G16	IPB424 × IPB373	Hybrid	20	G31	IPB420 × IPB373	Hybrid
G17	IPB421 × IPB424	Hybrid	21	Rawita F1	Rawita F1	Commercial variety (East-West Seed Indonesia)
G18	IPB421 × IPB420	Hybrid				
G19	IPB421 × IPB423	Hybrid	22	F1.373340	IPB373 × IPB372	Comparison
G21	IPB421 × IPB373	Hybrid	23	F1.373372	IPB373 × IPB340	Comparison

The observation characteristics consisted of plant height (cm), leaf area (cm^2), fruit length (cm), fruit diameter (cm), fruit weight (g), number of fruits per plant, marketable number of fruits, fruit yield per plant (g), marketable yield fruit (g), productivity (tons ha^{-1}), and leaf pigments (chlorophyll a (mg g^{-1}), chlorophyll b (mg g^{-1}), chlorophyll a/b ratio (mg g^{-1}), and total chlorophyll (mg g^{-1}) (Yudiansyah et al. 2024). Observations of microclimate components consisted of light intensity (lux), daily temperature (°C), and relative humidity (%). Light intensity was measured using a digital mini lux meter UT383. Daily temperature and relative humidity were measured using a USB temperature and humidity data logger.

Data analysis

Data were analyzed using a combined analysis of variance, followed by the Honest Significant Difference (HSD) test, and further tested at the 5% significance level using PKBT-STAT 3.1 (http://pbstat.com/pkbt-stat/). Plant tolerance levels were determined based on the relative production of plants (Sulistyowati et al. 2016). Based on these criteria, chili genotypes were grouped as follows: 1) shade-sensitive genotypes if relative production is <60%; 2) shade-moderate genotypes if relative production is 60%-80%; 3) shade-tolerant genotypes if relative production is 80%-100%; and 4) shade-loving genotypes if relative production is >100%. Pearson correlation was conducted using R*Studio* (*R version* 4.3.2). Cluster analysis was carried out based on "Euclidian dissimilarity" and "Complete linkage clustering method" using Microsoft Excel 2016 and Minitab 18 software.

RESULTS AND DISCUSSION

Microclimate under shade and unshaded conditions

The results of microclimate observations under shade, including light intensity (lux), daily temperature (°C), and relative humidity (%) are presented in Table 2. The utilization of paranet shade results in a reduction of light intensity and air temperature while increasing relative humidity. This observation aligns with the findings of Samanta and Hazra (2021) and Siahaan et al. (2023). The optimal light intensity for chili growth ranges from 35,000 to 50,000 lux, with daily temperatures ranging from 30 to 33°C (Samanta and Hazra 2021). Climatic variables are essential for the growth and physiological functions of plants, especially for C3 plants, which typically require moderate temperatures and optimal light conditions for efficient photosynthesis (Opoku et al. 2024).

Table 2. Microclimate under shaded and unshaded conditions

Variables	Unshaded condition	Shade condition
Light intensity (lux)	99,955	50,310
Daily temperature °C	34.74	32.70
Relative humidity (%)	75.07	81.75

Quantitative characterization of cayenne pepper genotypes

The results of the combined analysis of variance for 23 genotypes of cayenne pepper are presented in Table 3. Genotype significantly affected all observed traits, revealing genetic variation among the hybrid cayenne genotypes studied. The shade factor significantly influenced all traits except fruit yield per plant and number of fruits per plant, reflecting environmental differences between the test locations. The Genotype×Shade interaction (G×E) significantly affected most traits except the chlorophyll a/b ratio, plant height, and leaf area, suggesting environmental variability impacts genotype responses (Sivakumar et al. 2017). The proportion of the treatment's Mean Square (MS) to the total MS showed that most traits were more influenced by shading, except for fruit weight, which was more influenced by genetics. Traits with high genetic influence are ideal for selecting superior genotypes due to easier inheritance, enhancing selection efficiency and effectiveness. The Coefficient of Variation (CV) was below 20% for almost all variables, indicating data accuracy.

Shade and genotype significantly affected plant height and leaf area (Table 4). Plants in shaded conditions exhibited greater average height (128.08 cm) compared to those in unshaded conditions. Genotype G27 demonstrated the highest average height (126.54 cm), while G19 exhibited the lowest average height (78.55 cm). Shaded conditions also resulted in larger leaf areas (71.69 cm^2) compared to unshaded conditions (43.01 cm^2). Genotype G27 exhibited the largest leaf area (72.99 cm^2), with no significant differences observed among genotypes. The absence of a significant G×E interaction indicated similar responses across genotypes. Plants in shaded conditions were taller and had larger leaf areas than those in unshaded conditions, aligning with findings by Díaz-Pérez and John (2019) and Siahaan et al. (2022). Reduced light intensity under shaded conditions induces etiolation, an adaptive response to enhance light utilization (Khalid et al. 2019). Etiolation results from uneven auxin distribution, leading to stem elongation (Kusnetsov et al. 2020). Additionally, shade-grown plants increase leaf area and reduce leaf thickness to optimize photosynthesis under low light conditions (Díaz-Pérez 2013; Angmo et al. 2022).

Genotype, shade, and G×E interaction significantly influenced fruit length, fruit diameter, and fruit weight (Table 5). Shade increased fruit length (4.84 cm) compared to unshaded (4.28 cm). Genotype G26 exhibited the longest fruit in unshaded conditions (5.10 cm), while G22 demonstrated the longest fruit in shade (5.62 cm). Fruit diameter also varied significantly; G14 displayed the largest diameter in unshaded conditions (1.69 cm), whereas G8 and G31 exhibited the largest diameter in shade (1.61 cm). Shade resulted in greater fruit weight (2.95 g) compared to unshaded conditions. The highest fruit weight in the shade was observed in genotype G26 (3.45 g) and in unshaded conditions in G12 (3.31 g). Unshaded exposure reduces enzymatic activity and photosynthesis, decreasing photosynthates and negatively affecting growth and production (Díaz-Perez et al. 2020; Zhang et al. 2024).

Conversely, shaded plants, receiving less irradiation, produced larger fruits in terms of size and weight.

Genotype and the G×E interaction significantly influenced fruit number per plant, whereas shade treatment did not exhibit a significant effect (Table 6). Under unshaded conditions, genotype G16 exhibited the highest fruit number (126.07), while under shaded conditions, genotype G27 demonstrated the highest fruit number (161.70). Although 50% shade did not significantly impact the number of fruits per plant, it significantly increased the marketable number of fruits, with shaded conditions yielding 78.41 compared to 33.54 in unshaded conditions (Table 6). Genotype G10 produced the highest marketable number of fruits in unshaded conditions, though this was not significantly different from G29 (the lowest). Under shaded conditions, genotype G9 exhibited the highest marketable number of fruits (109.80).

Table 3. Analysis of variance of 23 cayenne pepper genotypes in two environments

Characters	Genotype (G)	Shade (E)	G×E	CV (%)
Fruit yield per plant	12.73**	51.76^{ns}	13.66**	13.15^{t}
Marketable yield fruit	9.52**	767.14**	11.82**	15.03^{t}
Number of fruits per plant	3.53**	42.80^{ns}	5.41**	12.42^{t}
Marketable number of fruits	5.56**	352.77**	5.74**	11.63^{t}
Productivity	0.28**	16.37**	0.35**	19.53^{t}
Fruit weight	1.02**	0.95**	0.07**	3.47
Chlorophyll a	0.10**	18.52**	0.12**	9.22
Chlorophyll b	0.02**	3.75**	0.02**	1.33
Chlorophyll a/b ratio	0.03**	1.36**	0.02^{ns}	4.35
Total chlorophyll	0.19**	38.89**	0.24**	9.42
Plant height	820.90**	90,557.48**	51.32^{ns}	9.41
Leaf area	1.32*	122.85**	0.02^{ns}	11.82^{t}
Fruit length	1.00**	10.90*	0.23**	6.66
Fruit diameter	0.10**	1.21**	0.05**	7.43

Note: CV: Coefficient of Variance; *: Significant effect at α: 5%; **: Significant effect at α: 1%; ns: No significant effect at α: 5%; t: transformed data ($\sqrt{x + 0,5}\sqrt{x + 0,5}$)

Table 4. Plant height and leaf area of 23 genotypes in two environments

Genotype	Plant height (cm)			Leaf area (cm^2)		
	N0	N50	Mean	N0	N50	Mean
G7	72.54	120.9	96.72^{c-f}	52.61	87.69	70.15^{a}
G8	88.78	147.97	118.37^{ab}	39.85	66.42	53.13^{a}
G9	82.83	138.05	110.44^{abc}	50.28	83.81	67.05^{a}
G10	76.44	127.4	101.92^{b-e}	49.53	82.54	66.04^{a}
G12	84.35	140.59	112.47^{abc}	39.52	65.87	52.69^{a}
G13	78.19	130.32	104.26^{bcd}	43.99	73.33	58.66^{a}
G14	77.32	128.87	103.10^{b-e}	38.87	64.77	51.82^{a}
G16	73.2	121.99	97.60^{b-f}	41.94	69.9	55.92^{a}
G17	74.4	123.99	99.20^{b-f}	35.63	59.39	47.51^{a}
G18	72.2	120.33	96.26^{c-f}	44.75	74.59	59.67^{a}
G19	58.91	98.18	78.55^{f}	45.15	75.25	60.20^{a}
G21	64.68	107.79	86.24^{def}	43.58	72.63	58.10^{a}
G22	76.24	127.07	101.65^{b-e}	40.82	68.04	54.43^{a}
G23	78.64	131.07	104.86^{bcd}	49.93	83.22	66.57^{a}
G24	61.77	102.95	82.36^{ef}	39.67	66.12	52.90^{a}
G26	87.45	145.75	116.60^{abc}	39.13	65.23	52.18^{a}
G27	94.91	158.18	126.54^{a}	54.74	91.24	72.99^{a}
G28	82.28	137.13	109.71^{abc}	32.44	54.06	43.25^{a}
G29	81.17	135.28	108.22^{abc}	39.63	66.04	52.84^{a}
G31	81.58	135.96	108.77^{abc}	40.77	67.95	54.36^{a}
Rawita F1	63.41	105.69	84.55^{def}	42.24	70.4	56.32^{a}
F1.373340	76.86	128.11	102.49^{b-e}	38.39	63.99	51.19^{a}
F1.373372	79.4	132.34	105.87^{a-d}	45.82	76.36	61.09^{a}
Mean	76.85^{B}	128.08^{A}		43.01^{B}	71.69^{A}	

Note: N0: Unshaded condition; N50: Shade condition. Numbers followed by the same lowercase letter within the same column and the same uppercase letter within the same row are not significantly different based on the HSD test at the 5% level

Table 5. Fruit length, stem diameter, and fruit weight of 23 genotypes in two environments

Genotype	Fruit length (cm)			Fruit diameter (cm)			Fruit weight (g)		
	N0	N50	Mean	N0	N50	Mean	N0	N50	Mean
G7	3.23^{e}	4.53^{bcd}	3.88^{fg}	1.08^{b-f}	1.45^{a-e}	1.27^{b-h}	2.74^{d-g}	2.89^{e}	2.82^{fg}
G8	3.50^{de}	4.46^{cd}	3.98^{d-g}	1.34^{bcd}	1.61^{a}	1.48^{ab}	3.15^{ab}	3.33^{a-d}	3.24^{ab}
G9	4.79^{ab}	5.05^{a-d}	4.92^{abc}	1.38^{ab}	1.59^{ab}	1.49^{a}	3.26^{ab}	3.31^{a-d}	3.29^{ab}
G10	4.40^{a-d}	5.30^{abc}	4.85^{abc}	1.15^{b-f}	1.22^{def}	1.19^{e-h}	2.74^{d-g}	2.58^{f}	2.66^{gh}
G12	4.64^{abc}	4.64^{bcd}	4.64^{a-d}	1.32^{bcd}	1.47^{a-e}	1.40^{a-e}	3.31^{a}	3.35^{abc}	3.33^{a}
G13	4.01^{b-e}	5.32^{abc}	4.67^{abc}	1.33^{bcd}	1.47^{a-e}	1.40^{a-e}	2.98^{bcd}	3.33^{a-d}	3.16^{a-d}
G14	4.43^{a-d}	4.43^{cd}	4.43^{c-g}	1.69^{a}	1.18^{ef}	1.43^{abc}	2.57^{fgh}	2.49^{f}	2.53^{hi}
G16	4.37^{a-d}	4.87^{a-d}	4.62^{a-e}	1.34^{bc}	1.56^{ab}	1.45^{abc}	2.83^{c-f}	3.05^{cde}	2.94^{def}
G17	4.29^{a-d}	4.49^{bcd}	4.39^{c-g}	1.23^{b-f}	1.24^{c-f}	1.24^{c-h}	2.20^{i}	2.53^{f}	2.37^{i}
G18	4.01^{b-e}	4.62^{bcd}	4.32^{c-g}	0.94^{f}	1.24^{c-f}	1.09^{gh}	2.38^{hi}	2.43^{f}	2.41^{i}
G19	5.09^{a}	5.32^{abc}	5.20^{ab}	1.24^{b-f}	1.36^{a-f}	1.30^{a-g}	2.95^{b-e}	3.05^{cde}	3.00^{c-f}
G21	4.04^{b-e}	4.60^{bcd}	4.32^{c-g}	1.06^{c-f}	1.37^{a-f}	1.21^{d-h}	2.60^{fgh}	2.44^{f}	2.52^{hi}
G22	4.76^{ab}	5.62^{a}	5.19^{ab}	1.17^{b-f}	1.52^{a-d}	1.35^{a-f}	3.19^{ab}	3.34^{abc}	3.27^{ab}
G23	4.34^{a-d}	5.17^{abc}	4.75^{abc}	1.11^{b-f}	1.44^{a-e}	1.28^{a-h}	2.80^{def}	3.02^{de}	2.91^{ef}
G24	4.80^{ab}	4.98^{a-d}	4.89^{abc}	1.15^{b-f}	1.19^{ef}	1.17^{fgh}	2.52^{f-i}	2.49^{f}	2.51^{hi}
G26	5.10^{a}	5.43^{ab}	5.27^{a}	1.31^{b-e}	1.60^{ab}	1.45^{abc}	3.14^{abc}	3.45^{a}	3.30^{ab}
G27	3.92^{b-e}	5.16^{abc}	4.54^{b-f}	1.25^{b-f}	1.60^{ab}	1.42^{a-d}	3.12^{abc}	3.39^{ab}	3.25^{ab}
G28	4.09^{b-e}	4.57^{bcd}	4.33^{c-g}	1.01^{ef}	1.29^{b-f}	1.15^{fgh}	2.46^{ghi}	2.45^{f}	2.46^{hi}
G29	4.13^{b-e}	4.69^{a-d}	4.41^{c-g}	1.35^{bc}	1.53^{a-d}	1.44^{abc}	2.76^{d-g}	3.43^{ab}	3.09^{b-e}
G31	4.42^{a-d}	4.95^{a-d}	4.69^{abc}	1.27^{b-e}	1.61^{a}	1.44^{abc}	2.64^{e-h}	3.25^{a-d}	2.95^{def}
Rawita F1	3.56^{de}	4.14^{d}	3.85^{g}	1.21^{b-f}	1.44^{a-e}	1.33^{a-f}	2.79^{def}	3.13^{b-e}	2.96^{def}
F1.373340	4.68^{abc}	4.82^{a-d}	4.75^{abc}	1.35^{bc}	1.55^{abc}	1.45^{abc}	3.15^{ab}	3.28^{a-d}	3.21^{abc}
F1.373372	3.78^{cde}	4.11^{d}	3.95^{efg}	1.03^{def}	1.10^{f}	1.07^{h}	1.64^{j}	1.74^{g}	1.69^{j}
Mean	4.28^{B}	4.84^{A}		1.23^{B}	1.42^{A}		2.78^{B}	2.95^{A}	

Note: N0: Unshaded condition; N50: Shade condition. Numbers followed by the same lowercase letter within the same column and the same uppercase letter within the same row are not significantly different based on the HSD test at the 5% level

Table 6. Number of fruits per plant and marketable number of fruits of 23 genotypes in two environments

Genotype	Number of fruits per plant			Marketable number of fruits		
	N0	N50	Mean	N0	N50	Mean
G7	112.33^{ab}	83.93^{ab}	98.13^{a}	48.78^{bc}	68.07^{a-e}	58.42^{a-f}
G8	59.67^{a-d}	149.87^{a}	104.77^{a}	27.33^{b-f}	118.80^{a}	73.07^{a-e}
G9	84.61^{a-d}	123.33^{ab}	103.97^{a}	38.56^{bc}	109.80^{ab}	74.18^{abc}
G10	125.17^{a}	86.64^{ab}	105.91^{a}	103.00^{a}	69.78^{a-e}	86.39^{a}
G12	44.75^{d}	111.67^{ab}	78.21^{a}	22.42^{c-f}	78.27^{a-e}	50.34^{c-f}
G13	77.45^{a-d}	57.73^{b}	67.59^{a}	34.67^{bc}	48.93^{de}	41.80^{c-f}
G14	89.00^{a-d}	109.95^{ab}	99.48^{a}	36.14^{bc}	88.02^{a-d}	62.08^{a-f}
G16	126.07^{a}	87.53^{ab}	106.80^{a}	56.93^{ab}	79.47^{a-e}	68.20^{a-d}
G17	98.44^{a-d}	112.20^{ab}	105.32^{a}	38.40^{bc}	73.50^{a-e}	55.95^{b-f}
G18	92.67^{a-d}	88.80^{ab}	90.73^{a}	21.31^{c-f}	65.93^{b-e}	43.62^{ef}
G19	89.27^{a-d}	96.33^{ab}	92.80^{a}	36.20^{bc}	70.40^{a-e}	53.30^{b-f}
G21	70.12^{a-d}	70.30^{b}	70.21^{a}	31.22^{b-e}	44.01^{e}	37.62^{f}
G22	83.18^{a-d}	82.47^{ab}	82.82^{a}	20.66^{c-f}	67.80^{a-e}	44.23^{ef}
G23	56.50^{a-d}	90.27^{ab}	73.38^{a}	33.22^{bc}	57.93^{cde}	45.58^{c-f}
G24	65.45^{a-d}	95.18^{ab}	80.32^{a}	24.11^{b-f}	57.53^{cde}	40.82^{f}
G26	49.50^{bcd}	107.73^{ab}	78.62^{a}	8.83^{ef}	79.00^{a-e}	43.92e^{f}
G27	72.00^{a-d}	161.70^{a}	116.85^{a}	42.08^{bc}	101.18^{abc}	71.63^{abc}
G28	112.17^{abc}	122.53^{ab}	117.35^{a}	28.00^{b-f}	87.53^{a-e}	57.77^{b-f}
G29	69.00^{a-d}	120.23^{ab}	94.61^{a}	7.67^{f}	93.09^{a-d}	50.38^{ef}
G31	82.78^{a-d}	96.13^{ab}	89.46^{a}	21.33^{c-f}	58.07^{cde}	39.70^{f}
Rawita F1	46.33^{cd}	96.82^{ab}	71.58^{a}	9.33^{def}	93.20^{abc}	51.27^{def}
F1.373340	108.03^{a-d}	103.33^{ab}	105.68^{a}	32.02^{bcd}	78.93^{a-e}	55.48^{b-f}
F1.373372	79.50^{a-d}	117.27^{ab}	98.38^{a}	49.23^{bc}	114.07^{ab}	81.65^{ab}
Mean	82.35	103.13		33.54^{B}	78.41^{A}	

Note: N0: Unshaded condition; N50: Shade condition. Numbers followed by the same lowercase letter within the same column and the same uppercase letter within the same row are not significantly different based on the HSD test at the 5% level

The genotype and genotype×shade interaction significantly influenced fruit yield per plant, whereas the shade treatment did not significantly affect this trait (Table 7). Genotype G27 produced the highest average fruit per plant (325.55 g), significantly exceeding F1.373372, which exhibited the lowest yield (124.41 g). Shade application affected genotypes variably; 14 genotypes demonstrated increased yield, while nine showed decreased yield. The average fruit yield per plant under shade conditions (232.08 g) did not differ significantly from unshaded conditions (196.16 g). However, shade significantly enhanced marketable fruit yield, with the highest marketable yield in unshaded conditions for genotype G10 (171.46 g) and under shade for G8 (254.78 g). Shade enhances the production and quality of cayenne pepper fruits (Ilic et al. 2017; Díaz-Perez et al. 2020) by modifying temperature and reducing carbohydrate utilization, thereby allocating more assimilates for growth and yield (Cruz et al. 2024). Furthermore, shade reduces anthracnose caused by *Colletotichum* spp., which can significantly impact yield (Saxena et al. 2016; Asare-Badiako et al. 2015; Mongkolporn and Taylor 2018).

The tolerance grouping of cayenne peppers was based on relative production values, defined as the percentage of fruit yield per plant under shade conditions compared to unshaded conditions. The genotypes were categorized into three groups: 60.87% shade-loving, 26.09% shade-tolerant, and 13.04% shade-moderate (Table 7). No genotypes were classified as shade-sensitive, which is consistent with the findings of Siahaan et al. (2022). This observation is likely attributable to the species *C. frutescens*, which exhibits superior performance under shade conditions compared to *C. annuum* L., indicating *C. frutescens*'s suitability for shade cultivation. Hybrid genotypes also demonstrate the benefits of heterosis (Karim et al. 2021; Labroo et al. 2021), maintaining optimal vigor and significantly increasing fruit yield under shade conditions.

Genotype, shade, and G×E interaction significantly influenced productivity characteristics (Table 8). The productivity of cayenne pepper under shaded conditions was significantly higher (4.68 tons ha^{-1}) than under unshaded conditions (2.21 tons ha^{-1}). Under unshaded conditions, the highest productivity was observed in genotype G16 (4.94 tons ha^{-1}), which differed significantly from G29 (0.34 tons ha^{-1}) and the comparison to Rawita F1 (0.41 tons ha^{-1}). Genotype G27 exhibited the highest productivity under shade (8.36 tons ha^{-1}), demonstrating a threefold increase compared to unshaded conditions.

Genotype, shade, and G×E interaction significantly influenced chlorophyll a, b, and total chlorophyll content, while the chlorophyll a/b ratio was affected by genotype and shade without their interaction (Table 9). Shade significantly increased chlorophyll a, b, and total chlorophyll, concomitantly reducing the chlorophyll a/b ratio. On average, shaded genotypes exhibited a 47.71% and 58.93% increase in chlorophyll a and b, respectively.

Table 7. Fruit yield per plant and marketable yield fruit of 23 genotypes in two environments

Genotype	Fruit yield per plant (g)					Marketable yield fruit (g)		
	N0	N50	Mean	Relative production (%)	Category	N0	N50	Mean
G7	271.80^{ab}	185.65^{bc}	228.73^{abc}	68	Shade-moderate	93.94^{ab}	139.93^{a-d}	116.93^{a-d}
G8	150.29^{abc}	351.26^{ab}	250.78^{ab}	234	Shade-loving	59.81^{bc}	254.78^{a}	157.29^{abc}
G9	227.02^{abc}	281.83^{abc}	254.42^{ab}	124	Shade-loving	80.77^{abc}	232.95^{ab}	156.86^{abc}
G10	227.74^{abc}	204.33^{bc}	216.04^{abc}	90	Shade-tolerant	171.46^{a}	129.73^{a-d}	150.60^{ab}
G12	115.61^{bc}	270.14^{abc}	192.87^{abc}	234	Shade-loving	40.25^{bc}	159.54^{a-d}	99.89^{a-d}
G13	202.45^{abc}	131.93^{c}	167.19^{bc}	65	Shade-moderate	69.34^{abc}	102.35^{cd}	85.84^{bcd}
G14	201.32^{abc}	202.31^{bc}	201.81^{abc}	100	Shade-loving	64.07^{bc}	147.32^{a-d}	105.70^{a-d}
G16	303.83^{a}	192.69^{bc}	248.26^{ab}	63	Shade-moderate	112.18^{ab}	157.74^{a-d}	134.96^{a-d}
G17	194.97^{abc}	222.04^{bc}	208.51^{abc}	114	Shade-loving	63.76^{bc}	123.75^{cd}	93.76^{bcd}
G18	213.83^{abc}	175.85^{bc}	194.84^{abc}	82	Shade-tolerant	44.19^{bc}	121.61^{bcd}	82.90^{cd}
G19	236.38^{abc}	218.29^{bc}	227.34^{abc}	92	Shade-tolerant	81.84^{abc}	139.95^{a-d}	110.90^{a-d}
G21	155.54^{abc}	154.26^{c}	154.90^{bc}	99	Shade-tolerant	55.68^{bc}	87.54^{d}	71.61^{d}
G22	244.44^{abc}	211.03^{bc}	227.74^{abc}	86	Shade-tolerant	45.18^{bc}	161.56^{a-d}	103.37^{a-d}
G23	126.62^{bc}	205.67^{bc}	166.15^{bc}	162	Shade-loving	58.59^{bc}	118.26^{bcd}	88.43^{bcd}
G24	144.65^{abc}	202.40^{bc}	173.52^{bc}	140	Shade-loving	47.51^{bc}	115.10^{bcd}	81.31^{cd}
G26	145.27^{abc}	268.03^{abc}	206.65^{abc}	185	Shade-loving	19.34^{c}	174.88^{a-d}	97.11^{cd}
G27	186.32^{abc}	464.77^{a}	325.55^{a}	249	Shade-loving	92.48^{ab}	252.49^{a}	172.49^{a}
G28	253.26^{abc}	261.40^{abc}	257.33^{ab}	103	Shade-loving	49.15^{bc}	194.07^{a-d}	121.61^{a-d}
G29	183.04^{abc}	302.47^{abc}	242.76^{ab}	165	Shade-loving	17.84^{c}	214.78^{abc}	116.31^{a-d}
G31	206.48^{abc}	252.94^{abc}	229.71^{abc}	122	Shade-loving	48.30^{bc}	130.97^{a-d}	89.63^{bcd}
Rawita F1	128.10^{bc}	191.77^{bc}	159.94^{bc}	150	Shade-loving	20.18^{c}	180.77^{a-d}	100.48^{bcd}
F1.373340	288.56^{ab}	241.91^{bc}	265.24^{ab}	84	Shade-tolerant	62.96^{bc}	174.19^{a-d}	118.58^{a-d}
F1.373372	104.06^{c}	144.75^{c}	124.41^{c}	139	Shade-loving	60.00^{bc}	139.95^{a-d}	99.98^{a-d}
Mean	196.16	232.08				63.43^{B}	158.88^{A}	

Note: N0: Unshaded condition; N50: Shade condition. Numbers followed by the same lowercase letter within the same column and the same uppercase letter within the same row are not significantly different based on the HSD test at the 5% level

Table 8. Productivity of 23 genotypes in two environments

Genotype	Productivity (tons ha^{-1})		
	N0	N50	Mean
G7	3.19^{abc}	4.36^{ab}	3.77^{a}
G8	0.85^{abc}	6.91^{ab}	3.88^{a}
G9	1.98^{abc}	6.25^{ab}	4.12^{a}
G10	0.95^{abc}	3.65^{ab}	2.30^{a}
G12	1.42^{abc}	5.44^{ab}	3.43^{a}
G13	2.55^{abc}	3.16^{ab}	2.86^{a}
G14	2.29^{abc}	4.69^{ab}	3.49^{a}
G16	4.94^{a}	3.97^{ab}	4.46^{a}
G17	3.33^{abc}	4.19^{ab}	3.76^{a}
G18	1.69^{abc}	3.79^{ab}	2.74^{a}
G19	4.19^{abc}	4.00^{ab}	4.10^{a}
G21	2.18^{ab}	2.68^{b}	2.43^{a}
G22	3.42^{abc}	4.57^{ab}	4.00^{a}
G23	1.24^{abc}	4.02^{ab}	2.63^{a}
G24	1.46^{abc}	3.97^{ab}	2.71^{a}
G26	1.05^{abc}	5.58^{ab}	3.31^{a}
G27	2.22^{abc}	8.36^{a}	5.29^{a}
G28	3.50^{abc}	5.16^{ab}	4.33^{a}
G29	0.34^{c}	5.32^{ab}	2.83^{a}
G31	1.84^{abc}	5.23^{ab}	3.53^{a}
Rawita F1	0.41^{bc}	3.60^{ab}	2.00^{a}
F1.373340	3.99^{abc}	5.31^{ab}	4.65^{a}
F1.373372	1.83^{abc}	3.38^{ab}	2.60^{a}
Mean	2.21^{B}	4.68^{A}	

Note: N0: Unshaded condition; N50: Shade condition. Numbers followed by the same lowercase letter within the same column and the same uppercase letter within the same row are not significantly different based on the HSD test at the 5% level

The greater increase in chlorophyll b compared to chlorophyll a under shade conditions results in a lower chlorophyll a/b ratio (Velitchkova et al. 2023), indicating plant adaptation to low light conditions to enhance photosynthetic efficiency (Zhu et al. 2017). This observation is consistent with findings on cayenne pepper, where low light conditions enhance chlorophyll a, b, and total chlorophyll while decreasing the chlorophyll a/b ratio (Goto et al. 2021; Siahaan et al. 2022).

Pearson correlation

Correlation analysis identified relationships between characters and factors affecting productivity under shade and unshaded conditions. Figure 1 presents these results. Under unshaded conditions, fruit yield per plant exhibited a significant positive correlation with marketable yield fruit (0.41), marketable number of fruits (0.33), and number of fruit per plant (0.90). This finding corroborates the research of Ganefianti et al. (2024), who observed a strong positive correlation between fruit yield per plant and number of fruits per plant. Positive correlation values with production characters can inform plant breeding programs to enhance yields through selection (Usman et al. 2016). Under shade conditions, fruit yield per plant correlated significantly with fruit diameter (0.40), plant height (0.65), marketable yield fruit (0.77), number of fruits per plant (0.89), marketable number of fruits (0.61), and fruit weight (0.39). Understanding these correlations is crucial in breeding programs to estimate yield improvements and identify high-yield, shade-tolerant genotypes.

Table 9. Chlorophyll a, b, a/b ratio, dan total chlorophyll of 23 genotypes in two environments

Genotype	Chlorophyll a (mg g^{-1})			Chlorophyll b (mg g^{-1})			Chlorophyll a/b Ratio (mg g^{-1})			Total chlorophyll (mg g^{-1})		
	N0	N50	Mean	N0	N50	Mean	N0	N50	Mean	N0	N50	Mean
G7	1.40^{ab}	2.12^{bcd}	1.76^{b}	0.50^{a}	0.86^{b-e}	0.68^{abc}	2.79	2.46	2.63^{ab}	1.90^{ab}	2.98^{cde}	2.44^{b}
G8	1.66^{ab}	2.07^{cd}	1.87^{ab}	0.62^{a}	0.82^{cde}	0.72^{abc}	2.71	2.53	2.62^{ab}	2.28^{ab}	2.88^{cde}	2.58^{ab}
G9	1.50^{ab}	2.39^{a-d}	1.95^{ab}	0.52^{a}	0.91^{a-e}	0.71^{abc}	2.90	2.63	2.77^{ab}	2.02^{ab}	3.30^{a-e}	2.66^{ab}
G10	1.36^{ab}	2.66^{ab}	2.01^{ab}	0.48^{a}	1.12^{a}	0.80^{abc}	2.83	2.39	2.61^{ab}	1.85^{ab}	3.78^{ab}	2.81^{ab}
G12	1.66^{ab}	2.27^{a-d}	1.97^{ab}	0.59^{a}	0.87^{b-e}	0.73^{abc}	2.79	2.61	2.70^{ab}	2.25^{ab}	3.15^{a-e}	2.70^{ab}
G13	1.70^{a}	2.18^{bcd}	1.94^{ab}	0.61^{a}	0.85^{b-e}	0.73^{abc}	2.77	2.57	2.67^{ab}	2.32^{ab}	3.03^{b-e}	2.67^{ab}
G14	1.45^{ab}	2.41^{a-d}	1.93^{ab}	0.53^{a}	0.90^{a-e}	0.71^{abc}	2.76	2.69	2.72^{ab}	1.98^{ab}	3.31^{a-e}	2.65^{ab}
G16	1.56^{ab}	2.07^{cd}	1.81^{ab}	0.54^{a}	0.82^{cde}	0.68^{abc}	2.88	2.54	2.71^{ab}	2.10^{ab}	2.89^{cde}	2.50^{ab}
G17	1.34^{ab}	2.03^{cd}	1.69^{b}	0.49^{a}	0.81^{cde}	0.65^{c}	2.75	2.50	2.62^{ab}	1.83^{ab}	2.84^{cde}	2.34^{b}
G18	1.13^{b}	2.23^{a-d}	1.68^{b}	0.44^{a}	0.88^{b-e}	0.66^{bc}	2.60	2.53	2.56^{ab}	1.57^{b}	3.11^{a-e}	2.34^{b}
G19	1.57^{ab}	2.22^{a-d}	1.90^{ab}	0.58^{a}	0.85^{b-e}	0.71^{abc}	2.80	2.62	2.71^{ab}	2.15^{ab}	3.07^{a-e}	2.61^{ab}
G21	1.60^{ab}	2.53^{abc}	2.07^{ab}	0.58^{a}	0.98^{a-d}	0.78^{abc}	2.76	2.61	2.69^{ab}	2.18^{ab}	3.51^{a-d}	2.85^{ab}
G22	1.24^{ab}	2.47^{abc}	1.85^{ab}	0.45^{a}	0.93^{a-e}	0.69^{abc}	2.76	2.66	2.71^{ab}	1.68^{ab}	3.39^{a-e}	2.54^{ab}
G23	1.65^{ab}	2.74^{a}	2.19^{a}	0.58^{a}	1.07^{ab}	0.83^{a}	2.83	2.55	2.69^{ab}	2.23^{ab}	3.81^{a}	3.02^{a}
G24	1.43^{ab}	2.18^{bcd}	1.80^{ab}	0.50^{a}	0.82^{cde}	0.66^{abc}	2.84	2.65	2.75^{ab}	1.93^{ab}	3.01^{b-e}	2.47^{b}
G26	1.56^{ab}	1.88^{d}	1.72^{b}	0.56^{a}	0.74^{e}	0.65^{c}	2.80	2.56	2.68^{ab}	2.11^{ab}	2.63^{e}	2.37^{b}
G27	1.71^{a}	2.33^{a-d}	2.02^{ab}	0.64^{a}	0.91^{a-e}	0.78^{abc}	2.67	2.56	2.62^{ab}	2.35^{a}	3.24^{a-e}	2.80^{ab}
G28	1.41^{ab}	2.18^{bcd}	1.80^{b}	0.52^{a}	0.90^{a-e}	0.71^{abc}	2.73	2.43	2.58^{ab}	1.93^{ab}	3.08^{a-e}	2.51^{ab}
G29	1.55^{ab}	2.54^{abc}	2.05^{ab}	0.62^{a}	1.03^{abc}	0.83^{ab}	2.55	2.47	2.51^{b}	2.18^{ab}	3.56^{abc}	2.87^{ab}
G31	1.74^{a}	2.08^{cd}	1.91^{ab}	0.62^{a}	0.77^{de}	0.70^{abc}	2.80	2.69	2.75^{ab}	2.37^{a}	2.85^{cde}	2.61^{ab}
Rawita F1	1.68^{ab}	2.16^{bcd}	1.92^{ab}	0.60^{a}	0.87^{b-e}	0.74^{abc}	2.82	2.51	2.67^{ab}	2.28^{ab}	3.03^{b-e}	2.66^{ab}
F1.373340	1.67^{ab}	2.30^{a-d}	1.98^{ab}	0.65^{a}	0.92^{a-e}	0.79^{abc}	2.58	2.49	2.54^{b}	2.32^{ab}	3.22^{a-e}	2.77^{ab}
F1.373372	1.63^{ab}	2.01^{cd}	1.82^{ab}	0.57^{a}	0.73^{e}	0.65^{c}	2.85	2.75	2.80^{a}	2.20^{ab}	2.75^{de}	2.47^{ab}
Mean	1.53^{B}	2.26^{A}		0.56^{B}	0.89^{A}		2.76^{A}	2.57^{B}		2.09^{B}	3.15^{A}	

Note: N0: Unshaded condition; N50: Shade condition. Numbers followed by the same lowercase letter within the same column and the same uppercase letter within the same row are not significantly different based on the HSD test at the 5% level

Cluster analysis

Cluster analysis categorizes genotypes into homogeneous groups based on similar traits. Euclidean distance quantifies genotype proximity, with smaller values indicating greater similarity (Tan et al. 2022). In this study, the grouping of genotypes was based on growth, yield, and physiological characters. The analysis of 23 cayenne pepper genotypes under unshaded conditions revealed six clusters at a 32% similarity level, shown in Figure 2. The primary distinguishing characteristics comprise number of fruits per plant, marketable fruit yield, marketable number of fruits, and leaf pigments (chlorophyll a, b, and total chlorophyll). Cluster I comprised genotypes G7 and G10 with a similarity of 44.14%. Cluster II consisted of G17, G28, G22, and G18 with v47.13%-78.40%. Cluster IV included G9, G14, and G24 with similarity 47.90%-55.11%. Cluster V contained one test genotype (G27) and one commercial variety (F1.373372) with a similarity of 35.50%. Cluster VI comprised G16, G19, and the comparison variety F1.373340 with similarity 46.13%-58.81%. High-yield genotypes were present in clusters I, II, and VI, while lower-yield genotypes were observed in clusters III, IV, and V.

The analysis of 23 cayenne pepper genotypes under shaded conditions revealed four clusters at a 26% similarity level, shown in Figure 3. The primary distinguishing characteristics comprise marketable yield fruit, number of fruits per plant, fruit yield per plant, productivity, and leaf pigments (chlorophyll a, b, and total chlorophyll). Cluster I comprise 13 genotypes, specifically G7, G18, G16, G19, G24, G14, G17, G28, G13, G22, G26, G31 and comparison varieties Rawita F1, with similarities ranging from 39.61-76.99%, whereas cluster II consists solely of the comparison F1. 373372, with a similarity of 24.66%. Cluster III encompasses 3 genotypes, namely G10, G23, and G21, with 55.03-73.33% similarity, while cluster IV comprises 6 genotypes, specifically G8, G27, G9, G12, G29 and the comparison F1.373340, with similarities of 37.02-81.00%. High-yield genotypes were present in clusters II and IV, while lower-yield genotypes were observed in clusters I and III.

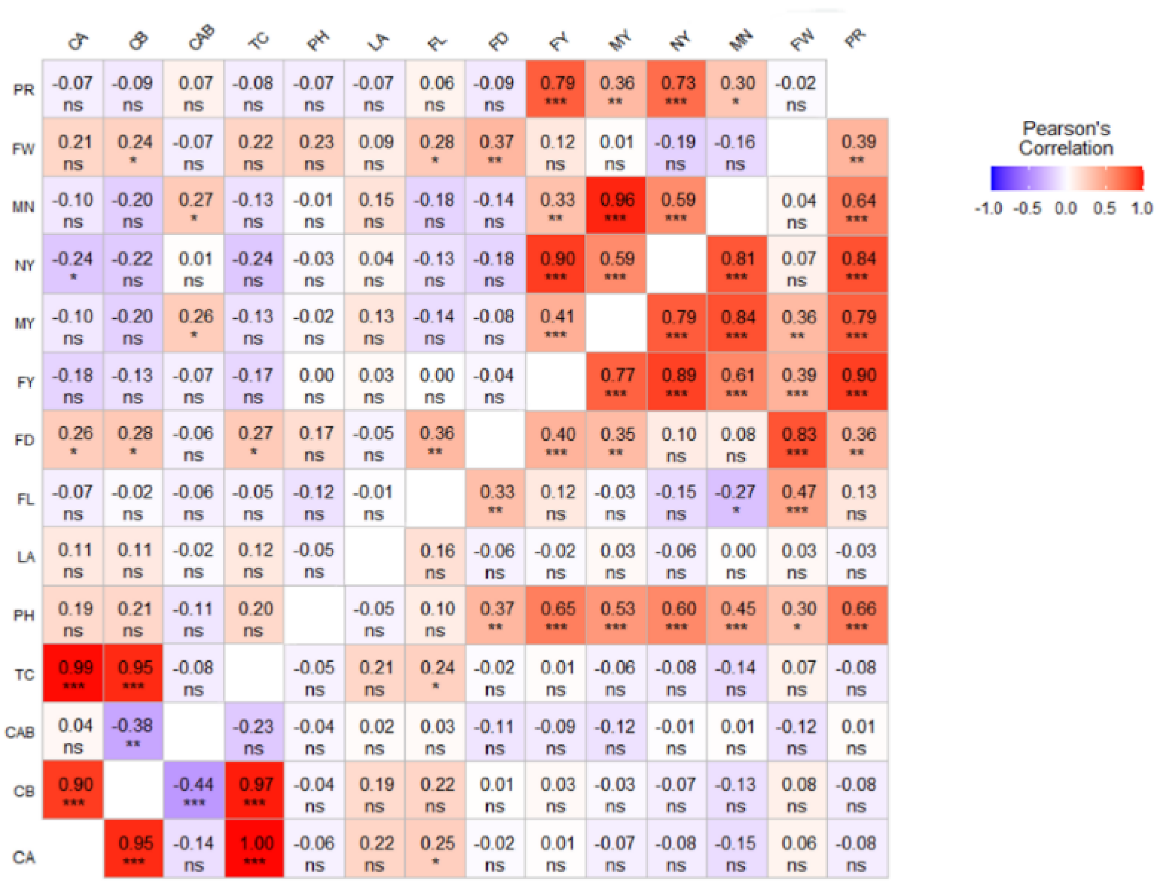

Figure 1. Correlation analysis of 23 Cayenne Pepper Genotypes for quantitative characters. Upward diagonal: Correlation value under unshaded condition; Downward diagonal: Correlation value under shade condition; CA: Chlorophyll a; CB: Chlorophyll b; CAB: Chlorophyll a/b ratio; TC: Total Chlorophyll; PH: Plant Height; LA: Leaf Area; FL: Fruit Length; FD: Fruit Diameter; FY: Fruit yield per plant; MY: Marketable fruit yield; FN: Fruit number per plant; MN: Marketable fruit number; FW: Fruit Weight; and PR: Productivity

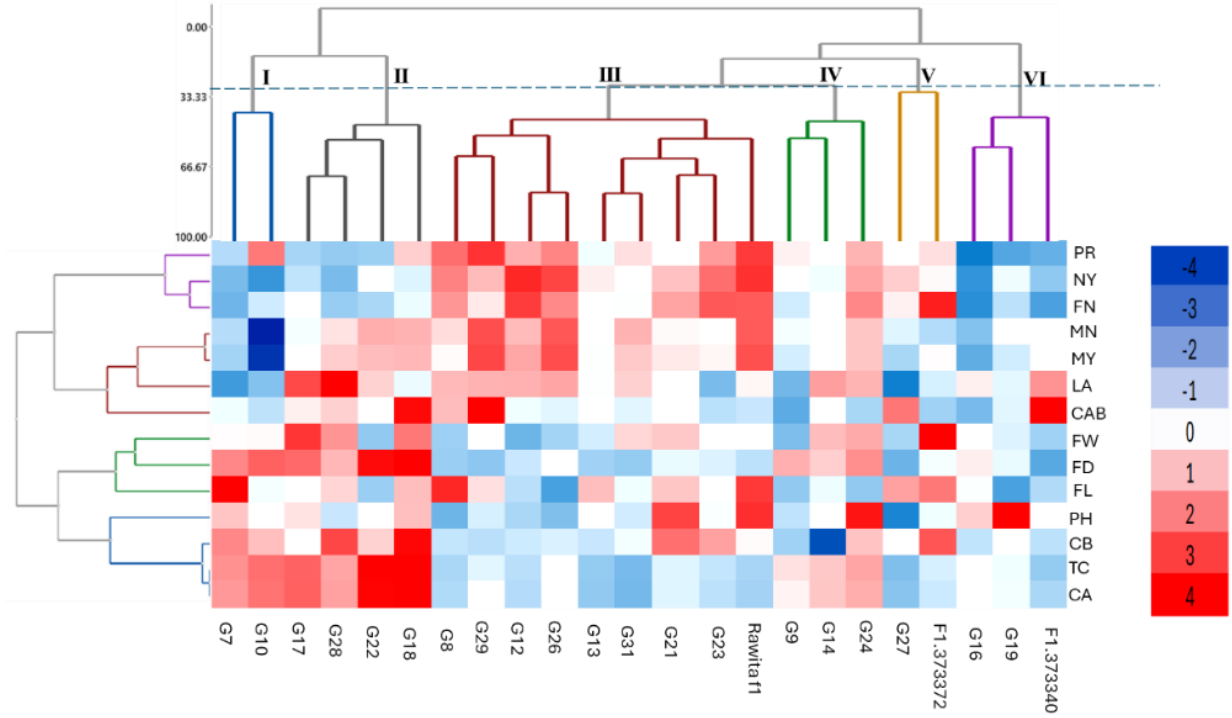

Figure 2. Cluster analysis of 23 genotypes of cayenne pepper hybrids under unshaded conditions. CA: Chlorophyll a; CB: Chlorophyll b; CAB: Chlorophyll a/b ratio; TC: Total Chlorophyll; PH: Plant Height; LA: Leaf Area; FL: Fruit Length; FD: Fruit Diameter; FY: Fruit yield per plant; MY: Marketable yield fruit; FN: Number of fruits per plant; MN: Marketable number of fruits; FW: Fruit Weight; and PR: Productivity

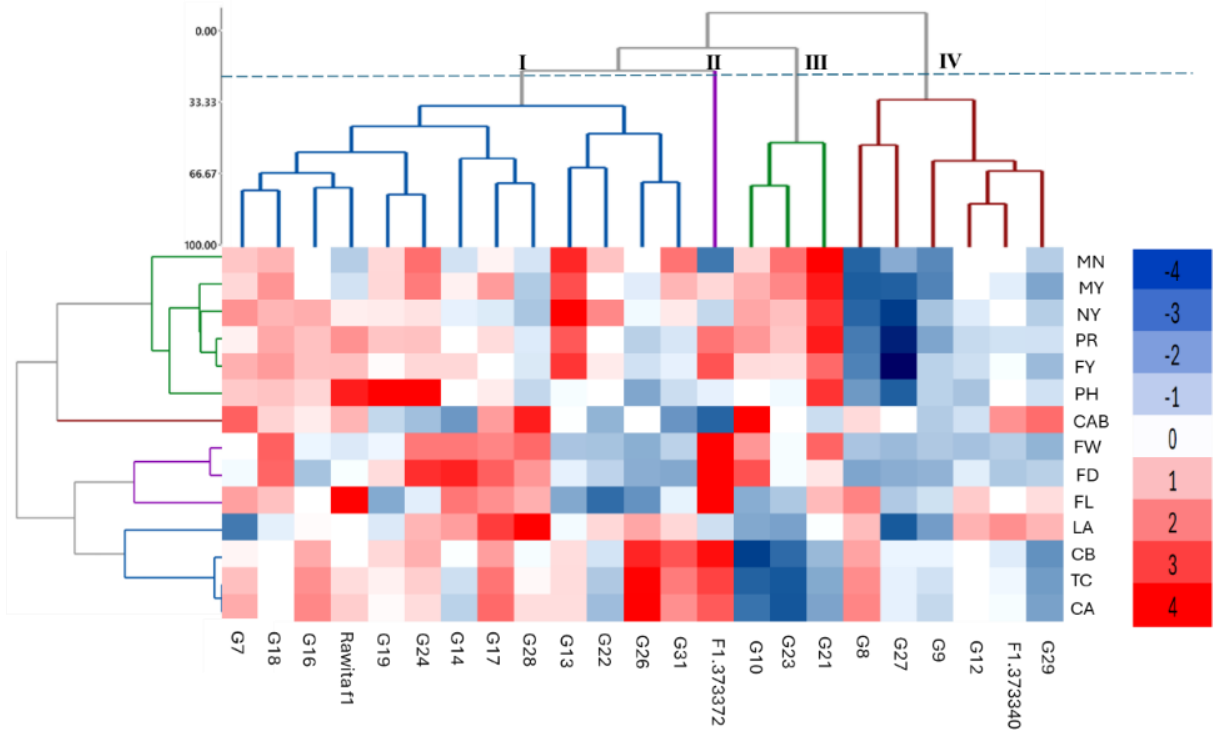

Figure 3. Cluster analysis of 23 genotypes of cayenne pepper hybrids under shaded conditions. CA: Chlorophyll a; CB: Chlorophyll b; CAB: Chlorophyll a/b ratio; TC: Total Chlorophyll; PH: Plant Height; LA: Leaf Area; FL: Fruit Length; FD: Fruit Diameter; FY: Fruit yield per plant; MY: Marketable yield fruit; FN: Number of fruits per plant; MN: Marketable number of fruits; FW: Fruit Weight; and PR: Productivity

In conclusion, genotypes G8 and G27 performed best under shade conditions, producing higher number of fruits per plant, fruit yield per plant, marketable number of fruits, marketable yield fruit, fruit diameter, and fruit weight compared to unshaded conditions. The application of a 50% shade net increased plant height, leaf area, fruit length, fruit diameter, fruit weight, marketable number of fruits, marketable yield fruit, and leaf pigments (chlorophyll a, b, and total chlorophyll). Chili was categorized into six clusters under unshaded conditions and four clusters under shaded conditions. Marketable fruit yield, marketable number of fruits, and number of fruits per plant had a significant positive correlation with fruit yield per plant under unshaded conditions. Under shaded conditions, fruit yield per plant showed a significant positive correlation with fruit diameter, plant height, marketable fruit yield, number of fruits per plant, marketable number of fruits, and fruit weight. Therefore, these traits can be used as selection criteria for developing hybrid chili varieties under both full-shade and unshaded conditions. These findings have practical implications for the development of hybrid chili varieties, providing valuable insights for agricultural researchers, horticulturists, and plant breeders interested in crop performance.

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