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RED BIRD PEPPER (*CAPSICUM FRUTESCENS* L.) GENETIC POTENTIAL IN RELATION TO YIELD AND RESISTANCE TO ANTHRACNOSE DISEASE

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SUMMARY

Anthracnose can cause yield losses of red bird pepper up to 80%, emphasizing the importance of developing new disease-resistant chili varieties. This research aimed to evaluate the 20 *C. frutescens* genotypes, comprising 11 commercial cultivars and nine advanced breeding lines, for morpho-yield-related traits and anthracnose disease resistance. The experiment layout in a randomized complete block design had three replications. The considerable correlation was evident for fruit weight per plant (0.97), fruit weight plot^{-1} (0.99), and fruit per plant (0.82). The number of fruit with symptoms showed a moderate correlation (0.54) to yield. The genotype Sona achieved the highest fruit yield (15.38 t ha^{-1}), followed by Ori (14.57 t ha^{-1}), Bonita (14.19 t ha^{-1}), and Feira (11.00 t ha^{-1}). Cultivars Ori and Hiyung exhibited a disease index below 20%, suggesting considerable resistance to anthracnose and sustained grouping in the same cluster, indicating a greater genetic potential as parent lines in breeding programs. Although cultivar Feira showed the maximum fruit yield, recorded with the most number of symptomatic fruits, it obtained a susceptible classification to anthracnose. These findings provide valuable insights for the development of red bird pepper cultivars with improved fruit yield and resistance to anthracnose.

Keywords: Red bird pepper (*C. frutescens* L.), cultivars, advanced lines, morphological traits, fruit yield, anthracnose disease, resistant and susceptible genotypes, cluster analysis

Key findings: Red bird pepper (*C. frutescens* L.) cultivars Ori and Hiyung revealed the highest fruit yield and were distinct as resistant to the anthracnose disease. In contrast, Feira acquired a susceptible classification to anthracnose despite its considerable yield.

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INTRODUCTION

Red bird pepper (*Capsicum frutescens* L.) is a widely cultivated crop due to its outstanding nutritional values (Egbe *et al.*, 2023; Moon *et al.,* 2023; Akor *et al.,* 2024; Nadzirah *et al.,* 2024) both in food and pharmaceutical industries (Muthuswamy *et al.,* 2021). The demand for red bird's eye chili in Indonesia is enormous, with an average weekly per capita expenditure of USD 0.11 (Rp 1,894.08 per weekly capita). But the supply is insufficient, with a production reaching only 83,765.19 tons (BPS, 2024, 2025). One of the causes of the low chili supply is the attacks of anthracnose disease.

Anthracnose disease attacks cause a limited availability of red bird pepper production. Anthracnose contributes to yield losses, ranging from 10% to 80% loss (Cui *et al.,* 2023). Khalimi *et al.* (2019) reported anthracnose disease attacks can spawn disease incidence in bird's eye chili (*Capsicum frutescens*) to reach 59%. The area affected by anthracnose disease in Indonesia reached 5,383.47 hectares in 2020, with a rise to 5,707.33 hectares in 2021 (Ministry of Agriculture, 2023).

Breeding for developing host resistance tended to be the most effective approach for controlling anthracnose in chili. Screening for a combination of various resistance sources and high-yield potential in inbred lines of the bird pepper remains limited. The development of anthracnose-resistant chili varieties proceeded through interspecific crossing between *C. annuum* and *C. chinense*, but the first-generation offspring (F1) exhibited high sterility (Voorips *et al*. 2004, Wei *et al.,* 2019). Kethom *et al*. (2023) stated the PBC80 accession of the *C. baccatum* species is resistant to *C. scoville*. In Indonesia, anthracnose-resistant varieties only comprise the *C. annuum* species (Kirana *et al*., 2014). *C. frutescens* exhibits resistance to anthracnose (Zhong *et al*. 2021), indicating its potential for development into a high-yielding, anthracnose-resistant variety. However, intraspecific breeding within *Capsicum frutescens* for anthracnose resistance has not yet reached documentation. Nonetheless, *C. frutescens* has been noteworthy as a potential source of the resistance trait of the red bird pepper. The main aim was to evaluate red bird pepper genotypes for high fruit yield and resistance to anthracnose under lowland growing conditions. Therefore, it is essential to identify the tolerant parental lines for use in future breeding programs.

Germplasm characterization is crucial for providing valuable insights to plant breeding programs in chili (Ratna *et al.,* 2024). Commercial cultivars and breeding lines served as germplasm resources. Both qualitative and quantitative morphological traits contribute significantly as yield components. Past studies revealed that qualitative morphological traits have been beneficial in cluster analysis based on multivariate data, with visualization through ordination using dissimilarity matrices (Pang *et al.,* 2023). Ordinal data, which involve ranking attributes in a specific order, are frequently applicable for effective morphological characterization. The presented study aimed to assess the genetic variability of 20 red bird pepper genotypes using both qualitative and quantitative morphological traits, thereby providing valuable information for breeding programs focused on high fruit yield and resistance to the anthracnose disease.

MATERIALS AND METHODS

Genetic material

The 20 *C. frutescens* genotypes comprised 11 commercial cultivars, i.e., Cakra Putih (Chia Tai Seed), Bonita IPB (IPB University), Feira IPB (IPB University), Hiyung (South Kalimantan), Inul (Tani Mandiri), Ori (Aura Seed), Prentul (Benih Unggul Sejati), Pulaipila Putih (Jogja Horti Lestari), Pulaipila Hijau (Jogja Horti Lestari), Sona (Jawara Seed), and Taruna (East West Seed Indonesia). These further included nine advanced breeding lines (RF-10, RF-13, RF-16, RF-17, RF-18, RF-25, RF-28, RF-32, and RF-39) procured from the Department of Agronomy and Horticulture, Faculty of Agriculture, IPB University, Bogor, Indonesia.

They underwent analysis for morphological traits related to fruit yield and anthracnose disease resistance.

Experimental design

The conducted experiment involved 20 genotypes of red bird peppers using a randomized complete block design with three replications at the Cibeureum Darmaga Research Farm, Bogor, Indonesia. Each pepper genotype had a 20-plant representation arranged in two rows in each replication. Planting distance used 40 cm × 60 cm for each plot. Obtaining climate data comprised the measurement of temperature and humidity.

Data recorded

Data collected on various traits included the total number of plants per plot, field emergence percentage, canopy diameter, stem length and diameter, days to flowering, and days to harvest. Fruit traits recorded consisted of the fruit pedicle length (cm), fruit length (cm), and fruit diameter (mm), along with flesh thickness (mm), measured at the widest part of a fruit's cross-section. Flesh thickness of healthy fruit samples entailed examination under a microscope at a 40× magnification, with images captured using a Samsung S20 smartphone before analysis within the Image-J software. Yield-related data included the number of fruits per plant, individual fruit weight (g), the total fruit weight per plant, and fruit weight per plot. The yield of fruit characters' observation came from the first to eighth harvesting. The percentage of disease incidence (PD) determination was at the onset of disease symptoms using the formula developed by Luis and Liestiany (2025):

$$\text{Percentage Disease} = \frac{\text{Number of infected fruit}}{\text{Total number of fruits per plant}}\ x\ 100\%$$

Resistance to anthracnose has succeeded categorization by following the methodology of Hasyim *et al.* (2014) based on disease incidence levels, with the following classifications: very resistant (0 < X < 10%), resistant (10 < X < 20%), moderate (20 < X < 40%), susceptible (40 < X < 70%), and very susceptible (>70%).

Productivity (t ha^{-1}) calculation relied on the formula of the Ministry of Agriculture (2019), as follows:

$$\left(\left(\frac{10.000}{length\ per\ plot\ x\ width\ per\ plot}\right) x \left(\frac{width\ per\ plot}{width\ per\ plot\ x\ width\ of\ ditc}\right)\right) x\ weight\ fruit\ per\ plot$$

Morphological characters' measurement depended on UPOV (2024), comprising leaf shape, fruit color before maturity, fruit length, diameter and shape, fruit sinuation at the basal part, fruit glossiness, and fruit shape apex. Observation of anthracnose disease symptoms continued naturally without artificial inoculation. Qualitative data of resistance to anthracnose for moderate gained classification into low, with moderate and susceptible classified into present.

Data analysis

Quantitative data obtained through agronomic evaluation underwent analysis of correlation (Schober *et al.,* 2018) and variance (ANOVA) using the PKBT-STAT version 3.2. The least significant difference (LSD) helped compare means. The ordinal data (UPOV 2024) comprising qualitative characters attained analysis using the NTSYS 2.02 software. Cluster analysis progressed with the Similarity for Interval Data (SIMINT). Dendrogram classification used the sequential, agglomerative, hierarchical, and non-overlapping (SAHN) and unweighted pair-group mean arithmetic (UPGMA) methods.

RESULTS

Genotypes' performance

The pepper cultivar Pulaipila Putih (G16) exhibited the highest plant count, with 19 plants per plot (95%), while RF10 (61.67%) and Cakra Putih (68.33%) had the lowest population, with approximately 12–13 plants per plot (Table 1). The plant growth structure can receive support from the diameter of its canopy, the thickness of stems, and stem height. In plant performance, the cultivar Sona provided the widest canopy diameter, RF18 recorded the tallest stem (48.88 cm), while line RF10 had the widest stem diameter (1.84 mm) (Table 1).

Floral characteristics include days to flowering and days to harvest. The cultivar Bonita was the earliest to flower after transplanting (58 days), which also recorded the early maturity for harvesting (94 days) after transplanting. The longest fruits resulted in the cultivar Pulaipila Putih (4.57 cm), while the cultivar Taruna produced the shortest fruit (2.48 cm). Fruit diameter in this study ranged from 0.54 to 1.38 cm, and the cultivar Hiyung had the fruit diameter at 0.54 cm (Table 1).

The pepper cultivar Bonita has the thickest flesh (583.18 µm) and the shortest fruit pedicle length (2.64 cm). Cultivars Ori (354) and Bonita (330) gave the most number of fruits per plant. Several pepper genotypes produced between 200 and 300 fruits per plant. In contrast, RF18 had the lowest yield, with only 79 fruits per plant (Table 2). The cultivar Inul showed the heaviest individual fruit weight (2.07 g). Cultivars Ori and Bonita had the maximum total fruit weight per plant (517.44 and 491.50 g, respectively). The cultivar Sona displayed the heaviest total fruit weight per plot (9,843.92 g) (Table 3). In terms of fruit yield, the cultivar Sona (G3) revealed the supreme fruit yield (15.38 t ha^{-1}), followed by cultivars Ori G17 (14.57 t ha^{-1}), Bonita G1 (14.19 t ha^{-1}), and Feira G14 (11.00 t ha^{-1}) (Table 2).

For the qualitative characters, the cultivar Feira exhibited a lanceolate leaf shape, while all other genotypes had ovate leaves (Table 3). The genotype RF-39 demonstrated a moderate degree of leaf margin undulation, while the other genotypes showed weak and no undulation. Fruit length categorization on observational data comprised three groups, i.e., short (2–2.9 cm), short to medium (2.9–3.9 cm), and medium (more than 4 cm). Cultivars Hiyung and Cakra Putih showed the shortest fruit length (Table 3). Fruit diameter also entailed four categories based on measurement data, viz., tiny (less than 0.65 cm), tiny to small (0.7–0.86 cm), small (0.865–1.025 cm), small to medium (1.03–1.19 cm), and medium (greater than 1.195 cm). The cultivar Hiyung produced the narrowest fruits (Table 3).

Pepper cultivars Hiyung and Cakra Putih exhibited a narrow triangular fruit shape with an acute fruit apex, while RF 18 and RF 39 showed a moderately triangular fruit shape (Table 3). The cultivar Pulaipila Putih had a medium level of pericarp sinuation at the basal part of the fruit (Table 3). The cultivar Pulaipila Hijau demonstrated a weak level of fruit glossiness (FG) (Table 3). Additionally, breeding lines RF 18 and RF 28 had the moderately depressed fruit apex, in contrast to the significant acute apex in the cultivars Hiyung and Cakra Putih (Table 3).

Cluster analysis is a widely used method in studying the genetic variability to identify morphological variations among the genotypes. The dendrogram succeeded in dividing into two main clusters at the variability coefficient of 1.34. Cluster 1 comprised genotypes RF-10, RF-13, RF-16, RF-17, RF-18, RF-25, RF-28, RF-32, RF-39, and cultivars Cakra Putih, Bonita IPB, Feira IPB, Hiyung, Inul, Ori, Prentul, Pulaipila Putih, Pulaipila Hijau, Sona, and Taruna. Meanwhile, the cultivars Ori and Hiyungin were in cluster 2, being resistant to the anthracnose disease (Figure 1). The promising red bird pepper genotypes hold significant potential for use in intraspecific breeding programs aimed at improving fruit yield and resistance to the anthracnose disease.

Tolerance analysis

The disease index percentage for anthracnose disease indicated 17 chili genotypes exhibited damage levels ranging from 20% to 54% (Table 4). However, the cultivars Ori and Hiyung showed the lowest disease incidence, ranging from 10% to 20% (Table 4), becoming classified as resistant. In contrast, lines RF10, RF17, RF18, RF25, RF28, and cultivars Feira, Taruna, and Cakra Putih attained the susceptible category, with disease incidence

Table 1. *Capsicum frutescens* L. genotypes with plant, leaf, and fruit characteristics.

Genotypes	Plants per plot (plant)	Field emergence (%)	Canopy diameter (cm)	Stem length (cm)	Stem diameter (mm)	Days to flowering (day)	Days to harvesting (day)	Fruit length (cm)	Fruit diameter (cm)
Bonita	18.67	93.33	114.47	36.22	1.25	58.00	94.00	3.14	0.94
Inul	18.67	93.33	104.59	43.88	1.28	65.33	111.00	3.85	1.38
Sona	18.67	93.33	136.44	46.90	1.40	69.00	105.00	3.55	1.15
Prentul	16.00	80.00	104.79	35.55	1.06	58.00	102.00	3.63	1.36
RF10	12.33	61.67	124.68	37.73	1.87	53.67	113.00	3.83	0.99
RF13	16.00	80.00	87.37	36.25	1.17	65.33	121.00	3.69	0.96
RF16	14.00	70.00	83.94	35.60	1.03	73.67	130.33	2.84	0.97
RF 17	16.33	81.67	84.05	30.89	1.03	69.00	116.00	3.74	1.07
RF18	14.33	71.67	106.47	48.88	0.97	77.00	137.33	2.81	1.14
RF25	15.33	76.67	118.93	41.90	1.14	70.00	127.67	3.08	0.98
RF28	16.33	81.67	98.91	32.11	1.10	65.33	115.00	3.59	0.86
RF32	13.33	66.67	104.61	39.93	1.08	69.00	125.00	3.44	0.83
RF39	15.00	75.00	109.72	37.62	1.03	58.00	116.00	3.41	0.92
Feira	16.67	83.33	103.87	34.00	0.98	65.33	104.67	3.98	0.80
Pulaipila Hijau	17.00	85.00	102.06	34.93	1.00	58.00	110.00	4.51	0.86
Pulaipila Putih	19.00	95.00	129.06	39.12	1.23	68.67	123.33	4.57	0.98
Ori	17.67	88.33	132.30	35.87	1.37	63.33	120.00	3.10	1.11
Taruna	14.67	73.33	77.34	37.16	0.92	60.00	127.67	2.49	0.77
Hiyung	17.67	88.33	100.46	32.03	1.03	69.00	130.67	2.51	0.55
Cakra Putih	13.67	68.33	74.30	29.73	0.79	68.00	130.67	2.80	0.61
Means LSD (5%)	-	-	23.81	9.33	0.45	18.91	31.09	0.60	0.26
Coefficient of variation (%)	15.65^{ns}	19.65^{ns}	13.73**	7.88**	23.74*	9.14**	8.30**	5.53**	8.49**

Note: Numbers followed by asterisk (*) is significant at *P* < 0.05, ** is very significant at *P* < 0.01, and ns is not significantly different at *P* < 0.01 based on the LSD test.

Table 2. *Capsicum frutescens* L. with various quantitative characteristics.

Genotypes	Flesh thickness (μm)	Fruit pedicle length (cm)	Days to anthracnose symptoms	Fruits per plant (fruit)	Fruit weight (g)	Fruit weight plant^{-1} (g)	Fruit weight plot^{-1} (g)	Yield (t ha^{-1})	Fruits with symptoms (fruit)	Percentage Disease (%)
Bonita	583.18	2.65	110.00	330.67	1.51	491.50	9,083.24	14.19	138.67	29.50
Inul	496.73	3.38	115.00	122.67	2.07	254.17	4,767.32	7.45	47.00	27.58
Sona	378.93	2.98	118.33	269.67	1.94	522.60	9,842.92	15.38	77.33	33.38
Prentul	294.07	3.41	124.00	177.67	1.68	296.14	4,418.13	6.90	79.33	31.38
RF10	598.89	3.76	123.67	80.33	1.86	144.87	1,790.20	2.80	61.00	42.26
RF13	370.61	3.69	134.33	89.67	1.34	120.12	1,917.65	3.00	40.00	31.01
RF16	286.58	3.31	143.67	122.00	1.47	176.53	2,776.65	4.34	41.00	35.19
RF 17	374.18	3.63	131.67	170.00	1.52	261.21	4,334.85	6.77	130.33	42.67
RF18	412.82	3.28	147.00	79.00	1.86	125.58	1,751.78	2.74	56.67	41.09
RF25	396.88	3.54	140.00	97.00	1.61	151.85	2,339.80	3.66	129.00	54.87
RF28	345.59	3.68	123.00	169.00	1.46	246.56	4,075.52	6.37	140.00	44.74
RF32	370.68	3.50	139.00	162.00	1.47	240.28	3,343.75	5.22	101.67	38.10
RF39	320.64	3.26	121.33	160.00	1.22	197.91	3,111.24	4.86	74.00	29.28
Feira	324.18	3.70	113.00	317.33	1.33	423.38	7,043.12	11.00	222.33	40.61
Pulaipila Hijau	408.17	3.89	123.67	211.00	1.61	338.53	5,850.90	9.14	135.00	38.18
Pulaipila Putih	424.29	3.72	130.67	158.00	1.71	277.89	5,279.97	8.25	115.67	41.80
Ori	438.85	2.89	144.33	354.00	1.45	517.44	9,326.83	14.57	73.33	16.46
Taruna	379.75	1.92	140.00	93.67	0.77	71.58	1,071.39	1.67	46.67	32.87
Hiyung	308.52	3.20	144.00	247.00	0.56	130.13	2,446.69	3.82	46.67	19.97
Cakra Putih	295.56	2.50	132.33	99.33	0.71	69.85	958.27	1.48	67.67	31.13
Means LSD (5%)	136.71	0.93	35.32	213.57	0.86	265.48	5,490.54	8.58	140.52	31.47
Coefficient of variation (%)	11.03**	8.84**	8.56**	33.33**	18.56**	33.07**	40.44**	33.07**	48.55**	28.24*

Note: Numbers followed by asterisk (*) is significant at $P < 0.05$, ** is very significant at $P < 0.01$, and ns is not significantly different at $P < 0.01$ based on the LSD test.

Table 3. *Capsicum frutescens* L. with various quantitative characteristics.

Genotypes	Leaf shape	Fruit color before maturity	Fruit length	Fruit diameter	Fruit shape	Fruit sinuation	Fruit glossiness	Fruit shape apex	Anthracnose
Bonita	Ovate	Greenish yellow	Short to medium	Small	Triangular	Weak	Medium	Moderately acute	Present
Inul	Ovate	Greenish yellow	Short to medium	Medium	Triangular	Weak	Medium	Moderately acute	Present
Sona	Ovate	Greenish yellow	Short to medium	Small to medium	Triangular	Weak	Medium	Moderately acute	Present
Prentul	Ovate	Greenish yellow	Short to medium	Medium	Triangular	Weak	Medium	Moderately acute	Present
RF10	Ovate	Greenish yellow	Short to medium	Small	Triangular	Weak	Medium	Moderately acute	Present
RF13	Ovate	Greenish yellow	Short to medium	Small	Triangular	Weak	Medium	Moderately acute	Present
RF16	Ovate	Greenish yellow	Short to medium	Small	Triangular	Weak	Medium	Moderately acute	Present
RF 17	Ovate	Greenish yellow	Short to medium	Small to medium	Triangular	Weak	Medium	Moderately acute	Present
RF18	Ovate	Greenish yellow	Short to medium	Small to medium	Rectangular	Weak	Medium	Moderately Depressed	Present
RF25	Ovate	Greenish yellow	Short to medium	Small	Triangular	Weak	Medium	Moderately acute	Present
RF28	Ovate	Greenish yellow	Short to medium	Small	Rectangular	Weak	Medium	Moderately Depressed	Present
RF32	Ovate	Greenish yellow	Short to medium	Tiny to small	Triangular	Weak	Medium	Moderately acute	Present
RF39	Lanceolate	Greenish yellow	Short to medium	Small	Triangular	Weak	Medium	Moderately acute	Present
Feira	Lanceolate	Greenish yellow	Short to medium	Tiny to small	Triangular	Weak	Medium	Moderately acute	Present
Pulaipila Hijau	Ovate	Green	Medium	Tiny to small	Triangular	Weak	Weak	Moderately acute	Present
Pulaipila Putih	Ovate	Greenish yellow	Medium	Small	Triangular	Medium	Medium	Moderately acute	Present
Ori	Ovate	Greenish yellow	Short to medium	Small to medium	Triangular	Weak	Medium	Moderately acute	Low
Taruna	Ovate	Greenish yellow	Short to medium	Tiny to small	Triangular	Weak	Medium	Moderately acute	Present
Hiyung	Ovate	Green	Short	Very small	Triangular	Weak	Medium	Strongly acute	Low
Cakra Putih	Ovate	Greenish white	Short	Very small	Triangular	Weak	Strong	Strongly acute	Present

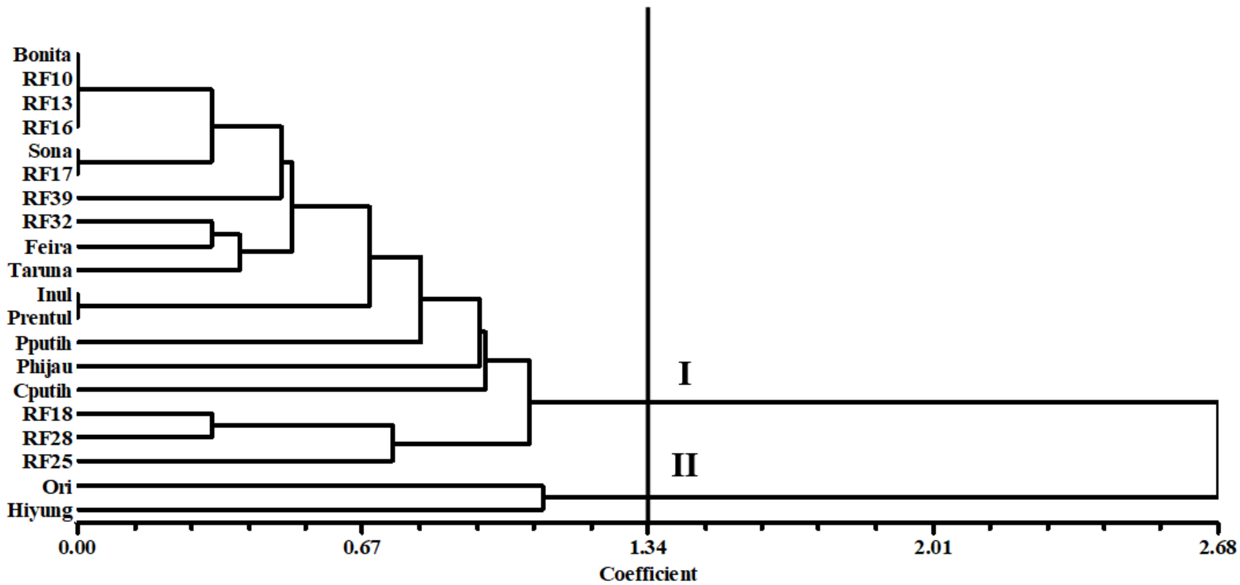

Figure 1. Dendrogram of clustering analysis for red bird pepper genotypes based on ordinal (simint-UPGMA) data from 9 qualitative traits.

Table 4. Resistance to anthracnose based on disease incidence levels (Hasyim *et al.,* 2014).

Score	Diseases incident (%)	Criteria	Genotypes
1	0 < X < 10	Highly resistant	-
2	10 < X < 20	Resistant	Ori, Hiyung
3	20 < X < 40	Moderate	Bonita, Inul, Sona, RF13, Prentul, RF16, RF32, RF39, Pulaipila Hijau, Pulaipila Putih
4	40 < X < 70	Susceptible	RF10, RF17, RF18, RF25, RF28, Feira, Taruna, Cakraputih
5	> 70	Very susceptible	-

levels ranging from 40% to 70% (Table 4). Cultivars Ori and Hiyung belonged to a group of the same cluster based on the dendrogram (Figure 1). They emerged as the promising red bird pepper genotypes for use in intraspecific breeding programs aimed at improving fruit yield and resistance to anthracnose disease.

Correlation tolerance to yield

Yield showed significant correlation to plants per plot, stem diameter, canopy diameter, days to harvesting, fruit length, fruit per plant, fruit width, fruit per plant, fruit weight, fruit weight plant^{-1}, and fruit weight plot^{-1}. Correlation coefficient categories had scoring as negligible (0.00–0.10), weak (0.10–0.39), moderate (0.40–0.69), strong (0.70–0.89), and very strong (0.90–1.00) (Schober *et al.,* 2018). The yield indicated a high correlation with fruit per plant (0.82), fruit weight per plant (0.97), and fruit weight plot^{-1} (0.99). The number of fruit with symptoms showed a moderate correlation (0.54) to yield (Table 5).

DISCUSSION

The germplasm morphological analysis offers important insights into the genetic diversity of *Capsicum frutescens* L. Dividing genetic variation typically results in two types, i.e., qualitative and quantitative traits. Quantitative traits assessment usually uses statistical tools, such as means, variances, standard deviation, and correlation. In plants, most traits of

Table 5. Correlation yield and other quantitative characters.

Characters	Plants per plot (plant)	Stem diameter (cm)	Canopy diameter (cm)	Days to harvesting (day)	Fruit length (cm)	Fruits per plant (fruit)	Fruit weight (g)	Fruit weight (g)	Fruit weight plot^{-1} (g)	Fruits with symptoms (fruit)	Yield (t ha^{-1})
Plants per plot (plant)	1	0.23	0.31*	-0.24	0.26*	0.44**	0.21	0.48*	0.62*	0.38	0.63**
Stem diameter (cm)	0.23	1	0.26	-0.27*	0.29*	-0.1	0.67**	0.33*	0.31*	0.03	0.30**
Canopy diameter (cm)	0,31*	0.26*	1	-0.13	0.28*	0.31*	0.41*	0.48*	0.48*	0.17	0.46**
Days to harvesting (day)	-0.24	-0.27	-0.13	1	-0.49**	-0.24	-0.34**	-0.45**	-0.42**	0.34*	-0.42**
Fruit length (cm)	0.26	0.29*	0.28	-0.49	1	0.11	0.49**	0.36**	0.35**	0.26	0.33**
Fruits per plant (fruit)	0.44**	-0.01	0.31*	-0.24	0.11	1	-005	-.83**	-.82**	0.43**	0.82**
Fruit weight (g)	0.21	0.67**	0.41**	-0.34	0.49*	-0.05	1	0.38**	0.36**-0.21	0.14	0.35**
Fruit weight (g)	0.47**	0.33*	0.48**	-0.45	0.36	0.84**	0.38**	1	0.97**	0.53	0.97**
Fruit weight plot^{-1} (g)	0.62**	0.31*	0.48**	-0.42**	0.34**	0.82**	0.36**	0.97**	1	0.54**	0.99**
Fruits with symptoms (fruit)	0.38**	0.03	0.17	-0.34	0.26	0.43**	0.14	0.53**	0.54**	1	0.54**
Yield (t ha^{-1})	0.63**	0.30*	0.47**	-0.42**	0.33**	0.82**	0.35**	0.97**	0.99**	0.54**	1

economic significance are the quantitatively inherited ones (Hakim *et al.,* 2023; Rustikawati *et al.*, 2025). Yield, as a quantitative trait, acquires influences from a combination of genetic factors and environmental conditions.

Environmental factors, particularly high temperatures reaching up to 40 °C, lead to decreased yields (González *et al.,* 2022). However, during this study period, the average temperature was 26.83 °C, which supported the production of over 100 flowers across 15 different pepper genotypes. Despite this, fruit set varied, affecting yield components, such as fruit diameter, length, weight, fruits per plant, the total number of plants per plot, and the total fruit weight per plot. Among the examined genotypes, cultivars Sona, Ori, Bonita, and Feira demonstrated the highest fruit yield, even if they produced fruits shorter than 5 cm.

Anthracnose disease, caused by the species *Colletotrichum*, significantly reduces yield by infecting chili fruits even during the early stages of ripening while the fruits are still green. In this study, all pepper genotypes received considerable effects from this disease. The cultivar Bonita, despite having the greatest flesh thickness at 583.18 µm, was the first to show the disease symptoms, with signs appearing as early as 110 days after transplanting. Contrastingly, cultivars Ori and Hiyung were the last genotypes to develop the disease symptoms, which emerged at 144 days after transplanting. The pathogen seemed to be seed-borne, as the field used in this study had previously grown cassava and had no prior history of chili cultivation. Species *Colletotrichum* can spread via rainwater splashes carrying conidia and through air dispersal (Abdila *et al.,* 2022). During this research, it was the rainy season. The rainy season plays a vital role in triggering anthracnose outbreaks, as elevated humidity and persistent moisture promote the disease's progression.

During the trial, the recorded average temperature was at 26.83 °C, with average humidity reaching 81.94%. Previous studies have demonstrated humidity levels around 80% and temperature close to 27 °C provide ideal conditions for the spread of anthracnose (Putra *et al.,* 2024). Chili breeding programs primarily aim to improve the fruit yield and enhance the resistance to diseases (Putra *et al.,* 2024). As such, identifying and screening genotypes for resistance to anthracnose is a crucial step (Kumar *et al.,* 2020). Genotypes were generally resistant when exhibiting a low level of disease incidence (Cui *et al.,* 2023). In a study by Luis and Liestiany (2025), the pepper cultivar Ori demonstrated disease incidence rates ranging between 4.20% and 15.59% during the fruiting stage. These findings were consistent with the presented results, where the cultivar Ori showed a disease incidence of 16.45%, classifying it as resistant, followed by the cultivar Hiyung with a relatively low incidence (19.96%). A moderate and significant correlation was evident between yield and the anthracnose disease. Ori appears to be a promising candidate for a parental line, as it possesses both high-yield potential and resistance to the anthracnose disease.

Qualitative traits, such as color, shape, presence or absence, structure, texture, and growth habit of flowers, fruits, and leaves, are examples of morphological markers. These characteristics sustained slight influences from environmental conditions. Qualitative traits can be effective for clustering analysis (Brzezi´nska and Łazarz, 2021). In studying genetic diversity, cluster analysis is widely advantageous to identify morphological variations among the genotypes, aiming to identify the potential parental lines for breeding programs. In this study, cluster analysis supported qualitative trait evaluation in 20 genotypes of the *Capsicum frutescens* L. The resulting dendrogram grouped the pepper genotypes into two main clusters at a variability coefficient of 1.34. The cultivar Feira entailed placement in the first group and has the triangular fruit shape, but with a consistent diameter from the base to the tip of the fruit, whereas other genotypes have a broader fruit base than the tip. However, this characteristic's description was not available in the UPOV guidelines. Cultivars Ori and Hiyung, being classified in cluster 2, demonstrated resistance to anthracnose disease, suggesting their suitability as parental lines in breeding programs targeting disease resistance. However, the susceptible pepper genotypes like Feira require further breeding efforts to improve their yield performance and resistance to the anthracnose disease.

CONCLUSIONS

Quantitative data analysis of 20 genotypes of red bird peppers (*C. frutescens* L.) revealed cultivars Sona, Ori, Bonita, and Feira were the highest-yielding. The cultivar Feira stood out for its highest fruit yield but also gained categorization as susceptible to the anthracnose disease. Cultivars Ori and Hiyung proved to be resistant to anthracnose and entailed grouping in the same cluster, indicating their considerable genetic potential as parental lines in future breeding programs aimed at improving anthracnose disease resistance. Conversely, although Feira demonstrated excellent yield performance, it requires further genetic improvement to enhance its disease resistance and agronomic traits.

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