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Evaluation of Seven Super-Hot Chili Pepper Genotypes (*Capsicum chinense*) for Developing High-Yielding and High-Quality Superior Varieties

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Abstract. This study evaluated seven promising super-hot chili genotypes (F1.383388, F1.382383, F1.383385, F5.382383-5-12-3, F4.382385-5-2, F4.382385-4-1, F6.382384-4-1-8-1) compared with four commercial varieties (Carolina Reaper, Katokkon, Red Bhut Jolokia, Mhanu) to identify candidates for developing high-yielding and high-quality superior varieties. A randomized block design with three replications was used at Bedugul, Bali (1200 m asl) from November 2024 to January 2026. Observations included qualitative and quantitative yield and quality traits. Results showed that genotype significantly affected all variables. Genotype F5.382383-5-12-3 exhibited the highest fruit weight per plant (1,268.00 g plant^{-1}) and number of fruits per plant (151.11 fruit plant^{-1}) with early harvest (112.00 dap), making it the best for productivity. Genotype F1.383385 showed superior quality traits, including the highest fruit length (7.07 cm), diameter (33.96 mm), placenta length (6.50 cm), and weight per fruit (13.84 g). Both genotypes are recommended for further multi-location trials as candidates for superior variety release. Correlation analysis revealed positive associations between fruit weight per plant and several fruit quality traits, indicating that higher-yielding genotypes also exhibited superior fruit quality. These findings provide a basis for selecting promising *Capsicum chinense* genotypes in breeding programs.

Keywords: *Capsicum chinense*; genotype evaluation; super-hot chili; superior variety; yield and quality

1. Introduction

Chili is one of the most economically important horticultural crops worldwide and plays a vital role in culinary, food processing, pharmaceutical, and nutraceutical industries. In Indonesia, chili consumption continues to increase with population growth and economic development. Data from the Central Statistics Agency (BPS, 2024) indicated that weekly per capita chili consumption increased from 0.13 kg in 2023 to 0.14 kg in 2024, reflecting the growing demand for chili at the household level. This increasing consumption emphasizes the need to improve production efficiency and develop superior cultivars capable of maintaining stable production. In modern chili breeding, yield remains the primary breeding objective because it directly affects farmers' income and production efficiency. However, fruit quality traits, including fruit size, shape, color, glossiness, and other market-preferred characteristics, are equally important because they determine consumer acceptance, processing suitability, and commercial value (Ortega Morales et al., 2025).

Bali, one of Indonesia's major culinary tourism destinations, has experienced a substantial increase in chili demand for both fresh consumption and processed products. Fluctuations in supply and demand continue to cause significant price instability, particularly during religious festivals and periods of peak consumption, highlighting the importance of developing high-yielding and widely adaptable cultivars to stabilize production (Wibowo et al., 2023; Muflikh & Kiloes, 2024). Although chili peppers are typically consumed in relatively small quantities, they play an important role in enhancing food flavor and overall sensory perception. Highly pungent chili cultivars can provide the desired level of spiciness with smaller amounts, thereby increasing their culinary efficiency (He et al., 2023). In parallel, consumer interest in highly pungent

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chili peppers has increased worldwide, driven by growing demand for novel sensory experiences and repeated exposure to spicy foods. Preference for highly pungent chili peppers is influenced by cultural background, repeated consumption, and individual characteristics, with younger consumers generally showing greater acceptance of spicy foods than older adults (Siebert et al., 2022). Spiciness is measured using the SHU (Scoville Heat Units), with classifications ranging from not spicy (900–1,999 SHU), slightly spicy (2,000–19,999 SHU), spicy (20,000–100,000 SHU), to very spicy (>100,000 SHU), whereas super-hot peppers exceed 100,000 SHU and have gained increasing popularity because of their distinctive flavor, culinary applications, and economic value (Amaliah, 2018; BSN, 2016). The expanding global demand for highly pungent peppers has encouraged breeding programs to develop cultivars combining superior pungency, high productivity, desirable fruit quality, and broad environmental adaptation (Hernandez-Perez et al., 2020; Wang et al., 2025).

Commercial cultivars such as Katokkon, Mhanu, Carolina Reaper, and Red Bhut Jolokia possess valuable agronomic and quality traits, including high pungency and unique fruit characteristics. Katokkon chili (*Capsicum chinense* Jacq.) is a leading horticultural commodity from the Toraja Highlands, Indonesia, distinguished by its characteristic aroma, unique bell-shaped fruits, and high pungency. These traits make it highly valued in traditional cuisine and an important regional specialty. Despite its desirable fruit quality, Katokkon generally exhibits relatively low productivity and is primarily adapted to cool highland environments, highlighting its potential as a valuable genetic resource for chili breeding programs (Dermawan et al., 2025; Al Amanah et al., 2024; Febrianty et al., 2024). Mhanu is a local cayenne pepper (Capsicum frutescens L.) characterized by small fruits and relatively high pungency, which makes it popular for fresh consumption and culinary applications. As a local genotype, Mhanu has potential as a genetic resource for breeding programs aimed at improving yield and fruit quality in Capsicum frutescens (Lalla et al., 2025; Putri et al., 2025). Carolina Reaper (*Capsicum chinense*) is widely recognized as one of the hottest chili cultivars in the world. Its pungency is primarily attributed to its exceptionally high capsaicinoid concentration, with reported values generally ranging from 1.4 to more than 2.2 million SHU. Besides its extreme pungency, Carolina Reaper has become an important genetic resource in breeding programs aimed at improving capsaicinoid content and fruit quality (Tanaka, 2025; Batiha et al., 2020). Red Bhut Jolokia (Ghost Pepper) is another highly pungent *Capsicum chinense* cultivar characterized by a distinctive fruity aroma and prolonged pungent sensation. It was the first chili cultivar reported to exceed one million SHU and has been extensively studied because of its high capsaicinoid content and potential applications in food, pharmaceutical, and agricultural industries (Tanaka, 2025; Batiha et al., 2020). Nevertheless, each cultivar also exhibits certain limitations, such as relatively low productivity or adaptation to specific environments, indicating that improvement is still required. Consequently, breeding strategies should focus on combining high yield, superior fruit quality, and wide adaptability within a single genotype. Because yield is a complex quantitative trait governed by multiple genetic and physiological processes, evaluation of yield should be integrated with fruit quality and physiological characteristics to improve the efficiency and accuracy of genotype selection.

To address the challenges, plant breeders at IPB University have developed seven advanced *Capsicum chinense* breeding lines consisting of three hybrid genotypes (F1.383388, F1.382383, and F1.383385) and four non-hybrid genotypes (F4.382385-5-2, F4.382385-4-1, F5.382383-5-12-3, and F6.382384-4-1-8-1). These breeding lines

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represent novel genetic combinations generated through systematic hybridization and selection and have shown promising yield and fruit quality in preliminary field evaluations conducted at the experimental farm of CV Benih Dramaga, Bogor, West Java. However, these breeding lines have not yet been released as commercial cultivars and require comprehensive evaluation before their superiority can be confirmed. Therefore, evaluation was conducted across representative agroecological regions, namely Bogor, Toraja, and Tabanan, which differ in altitude, temperature, rainfall, and cultivation practices. These locations were selected because they represent important chili-producing areas and provide contrasting environments for assessing genotype adaptability and stability. The breeding lines were also compared with four commercial check cultivars (Carolina Reaper, Katokkon, Red Bhut Jolokia, and Mhanu) to determine their relative agronomic performance and fruit quality.

Despite considerable progress in chili breeding, scientific information integrating yield performance, fruit quality, physiological characteristics, and the relationships among these traits as a basis for selecting superior *Capsicum chinense* genotypes remains limited. Most previous studies have focused on individual traits, particularly pungency or morphological characteristics, whereas comprehensive evaluation integrating agronomic, physiological, and fruit quality traits is still scarce. Such integrated evaluation is essential because breeding decisions should consider not only individual characteristics but also their interactions and collective contribution to overall plant performance. Therefore, this study aimed to evaluate the yield superiority, fruit quality, and relationships among agronomic and physiological traits of seven *Capsicum chinense* genotypes compared with four commercial cultivars. The results provide scientific evidence for identifying promising breeding lines, improving indirect selection strategies in Capsicum breeding, and supporting the development of superior super-hot chili cultivars with high productivity, excellent fruit quality, and broad adaptability for both fresh consumption and the food processing industry.

2. Materials and Methods

This study evaluated seven promising super-hot chili genotypes for their potential as high-yielding and high-quality superior varieties. A one-factor randomized block design was used with 11 genotype levels: 3 expected hybrid genotypes, 4 expected non-hybrid genotypes, and 4 comparative varieties. The genotypes were F1.383388 (G1), F1.382383 (G2), F1.383385 (G3), F5.382383-5-12-3 (G4), F4.382385-5-2 (G5), F4.382385-4-1 (G6), F6.382384-4-1-8-1 (G7), Carolina reaper (G8), Katokkon (G9), Red Bhut Jolokia (G10), and Mhanu (G11). Three replications resulted in 33 experimental units. Each experimental unit contained 24 plants, but only 12 sample plants were observed. Yield components and quality traits essential for superior variety development were assessed. Seed sowing was in Juwuklegi, Batunya (Bali Gumitir), while planting was in Greenhouse Auretta Villa, Taman Tanda, Bedugul, Tabanan, Bali (altitude ±1200 meters above sea level/m asl). The average temperature ranged from 18 to 25°C, with relative humidity between 75% to 90%. These environmental conditions were generally favorable for chili growth; however, the relatively lower temperatures compared with lowland areas may have influenced the rate of plant growth, flowering, and fruit development. Laboratory analyses (leaf N, P, K, total sugar) were conducted at Udayana University. The study ran from November 2024 to January 2026.

Materials included chili seeds, seedling media (charcoal husk:manure:soil = 1:1:1), AB Mix fertilizer, pesticides, and supporting tools. Equipment included a SPAD-502 chlorophyll meter, digital scales, and standard agricultural tools. Standard evaluation protocols for identifying superior genotypes were followed. Procedures

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included site survey, seed sowing, bed preparation, planting, maintenance, harvesting, seed extraction, sampling, and laboratory analysis. Seeds were sown in 72-hole trays (one seed/hole) with regular watering and fertilization. Seedlings were transplanted at 6 weeks after sowing. Beds had 50 cm × 50 cm spacing. Maintenance included watering, replanting, staking, pruning, fertilization (AB Mix twice weekly), pest control, and weed management. Harvesting was at 100–150 days after planting, every 3–5 days. Seeds were manually extracted and dried for 2–3 days.

Qualitative traits were assessed using a scoring method: 1) flower shape: rotating (1), campanulate (2), others (3); 2) fruit shape: oblate (1), circular (2), cordate (3), square (4), rectangular (5), trapezoidal (6), moderately triangular (7), narrowly triangular (8), horn shaped (9); 3) fruit cross-section: un-wavy (1), slightly wavy (2), very wavy (3); 4) curly curves at fruit base: none (1), little (2), medium (3), lot (7), very abundant (9); 5) fruit tip shape at ripening: pointed (1), blunt (3), rounded (5), notched (7), very notched (9); 6) fruit color: intermediate (white (1), yellow (2), orange (3), green (4), purple (5), purple-brown (6), brown (7)) and ripe (white (1), yellow (2), orange (3), red (4), brown (5), green (6)); 7) fruit base shape: pointed (1), blunt (2), shallow (3), medium (4), curved (5); 8) placenta color: white (1), yellowish white (2), yellow (3), orange (4), red (5); 9) seed color: dark yellow (3), brown (5), black (7); 10) fruit surface gloss: weak (3), medium (5), strong (7); 11) fruit stalk color: light green (1), green (2), dark green (3), purple (4). All were observed at the 2nd or 3rd harvest.

The following quantitative characters were measured as indicators of yield potential and fruit quality: (1) flowering age (days after planting/dap) at 50% flowering; (2) harvest age (dap) at 50% harvest-ready fruits; (3) weight per fruit (g) from 10 fruits/replication at 2nd/3rd harvest using a digital scale; (4) fruit length (cm) from base to tip (10 fruits/replication); (5) fruit stalk length (cm) from fruit base to stalk end; (6) fruit diameter (mm) at widest part using caliper; (7) pulp thickness (mm) at thickest part; (8) placenta length (cm) from base to end; (9) 1000 seed weight (g) from ten repetitions of 100-seed weights; (10) number of fruits per plant (fruit plant^{-1}) from 1st to 10th harvest; (11) fruit weight per plant (g plant^{-1}) accumulated from 1st to 10th harvest; (12) Leaf chlorophyll content (SPAD units) was measured twice, at the flowering stage (40–50 days after transplanting, dat) and the fruiting stage (>65 dat), using a SPAD-502 Chlorophyll Meter. Leaf samples were collected from the lower, middle, and upper canopy of each plant, with two fully expanded leaves selected from each canopy position. Chlorophyll was measured at five points per leaf, and the average value was automatically calculated using the instrument's Average function; (13) Leaf nitrogen (N), phosphorus (P), and potassium (K) contents (%) were analyzed using composite leaf samples collected from the lower, middle, and upper canopy during the flowering and fruit development stages. Total nitrogen was determined using the Kjeldahl method, while phosphorus and potassium were analyzed using the Olsen and Bray extraction methods, respectively; (14) Total leaf sugar content (%) was determined using the Anthrone method. Composite samples of fully expanded leaves collected from the lower, middle, and upper canopy were transported to the laboratory in a cool box, oven-dried at 80°C to constant weight, ground into a fine powder, and stored in airtight labeled plastic bags before analysis at the Laboratory of Agricultural Product Technology, Faculty of Agricultural Technology, Udayana University.

Data were compiled using Microsoft Excel version 2508 (Build 19127.20302) and analyzed using analysis of variance. Experimental precision was evaluated using the coefficient of variation (CV). To determine whether genotype differences significantly affected yield and quality traits, further analysis was conducted using the Honest Significant Difference test (HSD) at

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5% and 1% significance level with PKBT STAT 3.2 software. The statistical analyses were performed only for the yield- and fruit quality-related traits. Leaf N, P, K, and total leaf sugar contents were measured only as supporting physiological parameters and were therefore summarized descriptively without inferential statistical analysis.

3. Results and Discussion

The analysis of variance revealed that genotype had a very significant effect on all yield and quality variables ($p<0.01$), confirming that genetic factors play a dominant role in determining crop productivity and quality. This finding provides the fundamental basis for developing high-yielding and high-quality superior varieties, as some genotypes demonstrated superior combinations of high yield and good fruit quality, making them potential candidates for variety release.

Table 1 presents the qualitative traits of all genotypes. Genotype F1.383385 consistently exhibited superior fruit morphology with the highest fruit shape value (7.67), which was not significantly different from F1.383388, F5.382383-5-12-3, F4.382385-4-1, F6.382384-4-1-8-1, and Katokkon. The lowest fruit shape values were recorded in F1.382383, Carolina Reaper, and F4.382385-5-2. Regarding fruit cross-section, Carolina Reaper and Red Bhut Jolokia showed the highest values and were significantly different from other genotypes, while Mhanu had the lowest value, contrasting sharply with all others. In terms of fruit curly curves, Carolina Reaper and F1.383385 showed the highest values, not significantly different from each other, whereas Mhanu again recorded the lowest value. Fruit tip shape analysis placed Carolina Reaper highest, starkly contrasting with most other genotypes, with Red Bhut Jolokia not significantly different from Mhanu.

The lowest tip shape values were found in F6.382384-4-1-8-1, F4.382385-4-1, F1.383388, and F5.382383-5-12-3. Concerning old fruit color, most genotypes including F1.383388, F1.382383, F1.383385, F5.382383-5-12-3, F4.382385-5-2, Carolina Reaper, Katokkon, Red Bhut Jolokia, and Mhanu exhibited red color and were not significantly different from each other. Genotype F6.382384-4-1-8-1 showed a significantly different orange color, while F4.382385-4-1 had the lowest yellow color value, significantly different from all other genotypes (Figure 1). These morphological variations are essential for assessing visual fruit quality. Heydari et al. (2019) stated that these characters are important to observe in plant breeding programs because diversity in morphological characters reflects genetic diversity. Fruits with superior characteristics are usually prioritized for sale in supermarkets and export markets, thus having higher selling value. For developing superior varieties, genotypes like F1.383385 that combine multiple desirable morphological traits are particularly valuable.

Table 2 summarizes additional qualitative traits and flowering age. Carolina Reaper achieved the highest fruit base shape score, contrasting with Mhanu, which recorded the lowest value, significantly different from other genotypes. Seed color values for most genotypes ranged between 2.33-3.00 without significant differences, except F4.382385-4-1 which had the lowest value, significantly different from all others. Fruit gloss values were consistently high (6.48-7.00) for most genotypes, but Red Bhut Jolokia exhibited the lowest value, contrasting sharply with all other genotypes. For fruit stalk color, Carolina Reaper had the highest value, followed by Red Bhut Jolokia, Mhanu, and F6.382384-4-1-8-1, while F1.382383, F4.382385-4-1, and Katokkon had the lowest values. Placental color was highest in F1.382383 and F5.382383-5-12-3, while F4.382385-4-1 had the lowest value. The color and shine of the fruit are closely related to pigment content and genetically controlled epidermal structure. Fruit appearance is associated with pigments such as chlorophyll, carotenoids, and

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anthocyanins, which change during fruit development and ripening (Kapoor et al., 2022). During ripening, chlorophyll degrades, causing loss of green color and increased accumulation of carotenoids and anthocyanins that produce yellow, orange, red, and other colors (Chen et al., 2022). These pigments serve as visual indicators of ripening and enhance fruit attractiveness (Kapoor et al., 2022). Their composition is influenced by genetic, physiological, and environmental factors during development (Zhao et al., 2023). The color of the fruit stalk and placenta is related to pigment content and plant genetic expression. High values in fruit stalk and placenta colors indicate stable genetic expression and good physiological tissue quality, contributing to overall fruit quality. Therefore, genotypes with consistently high scores for these visual quality traits, such as F1.383385 and F5.382383-5-12-3, are strong candidates for superior variety development.

Table 1. Fruit Shape, Fruit Cross Section, Fruit Curly Curve, Fruit Tip Shape, and Color of Old Fruit in Some Super Spicy Chili Genotypes

Genotype	Fruit Shape	Fruit Cross Sections	Fruit Curly Curves	Fruit Tip Shape	Color of Old Fruit
F1.383388	6.32 ± 0.52^{ab}	2.03 ± 0.05^{b}	3.72 ± 0.15^{cd}	1.73 ± 0.57^{d}	4.00 ± 0.00^{a}
F1.382383	3.06 ± 0.42^{d}	2.00 ± 0.00^{b}	2.39 ± 0.35^{de}	4.22 ± 1.84^{bcd}	4.00 ± 0.00^{a}
F1.383385	7.67 ± 1.15^{a}	2.00 ± 0.00^{b}	5.67 ± 1.15^{a}	4.33 ± 3.06^{bcd}	3.67 ± 0.58^{a}
F5.382383-5-12-3	6.95 ± 0.05^{ab}	2.08 ± 0.00^{b}	4.17 ± 0.44^{bc}	1.78 ± 0.35^{d}	4.00 ± 0.00^{a}
F4.382385-5-2	3.50 ± 0.66^{d}	1.97 ± 0.10^{b}	2.61 ± 0.38^{de}	2.61 ± 0.98^{cd}	4.11 ± 0.38^{a}
F4.382385-4-1	6.42 ± 0.94^{ab}	2.11 ± 0.05^{b}	3.39 ± 0.19^{cde}	1.33 ± 0.17^{d}	2.00 ± 0.00^{c}
F6.382384-4-1-8-1	6.56 ± 0.51^{ab}	1.92 ± 0.08^{b}	2.83 ± 0.29^{cde}	1.28 ± 0.19^{d}	3.00 ± 0.00^{b}
Carolina Reaper	3.11 ± 0.19^{d}	3.00 ± 0.00^{a}	6.67 ± 0.29^{a}	9.00 ± 0.00^{a}	4.00 ± 0.00^{a}
Katokkon	6.00 ± 0.73^{ab}	2.08 ± 0.08^{b}	3.50 ± 0.44^{cde}	2.72 ± 0.69^{cd}	4.00 ± 0.00^{a}
Red Bhut Jolokia	3.88 ± 0.76^{cd}	2.92 ± 0.14^{a}	5.28 ± 0.05^{ab}	6.50 ± 0.50^{ab}	4.00 ± 0.00^{a}
Mhanu	5.43 ± 0.29^{bc}	1.06 ± 0.10^{c}	2.24 ± 0.43^{e}	5.76 ± 0.88^{abc}	4.00 ± 0.00^{a}
HSD 5%	1.91	0.22	1.41	3.53	0.64

Note: Numbers followed by the same letter in the same column are not significantly different from the 5% HSD test.

Flowering age varied significantly among genotypes. Mhanu recorded the highest value (62.33 dap), contrasting with Carolina Reaper (60.67 dap), while F4.382385-4-1 had the lowest value (43.33 dap), not significantly different from F1.382383 (45.00 dap). Similarly, harvest age showed Mhanu with the highest value (152.00 dap), starkly contrasting with most other genotypes, while F5.382383-5-12-3 had the lowest value (112.00 dap), significantly different from other genotypes (Table 3). Flowering age and harvest age are important indicators of plant adaptation and genotype growth strategies. Longer flowering and harvest periods indicate slower transition to the generative phase and physiological maturity, generally associated with greater biomass accumulation and yield potential. In contrast, shorter periods reflect faster life cycle completion, providing advantages under limited environmental conditions (Kopta et al., 2019; Muntaha et al., 2023; Ronga et al., 2019). For developing superior varieties, F5.382383-5-12-3 offers the advantage of early harvest (112 dap) combined with high yield, allowing more planting cycles per year.

Turning to yield components, weight per fruit was highest in F1.383385 (13.84 g), F5.382383-5-12-3 (12.67 g), and Katokkon (12.54 g), while Red Bhut Jolokia (5.34 g) and Mhanu (4.85 g) had the lowest values. The number of fruits per plant was highest in F5.382383-5-12-3 (151.11 fruits plant^{-1}), followed by F1.383385 (125.33 fruit plant^{-1}), while Carolina Reaper had the lowest (28.75 fruits). Most importantly, fruit weight per

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plant, the key productivity indicator, was highest in F5.382383-5-12-3 (1,268.00 g plant⁻¹), followed by F1.383385 (1,095.53 g plant⁻¹), while Carolina Reaper, Red Bhut Jolokia, and Mhanu had the lowest yields. Weight per fruit reflects fruit size and individual development influenced by cell division, enlargement, and photosynthate availability during fruit filling (Singh et al., 2024; Sowmya et al., 2023).

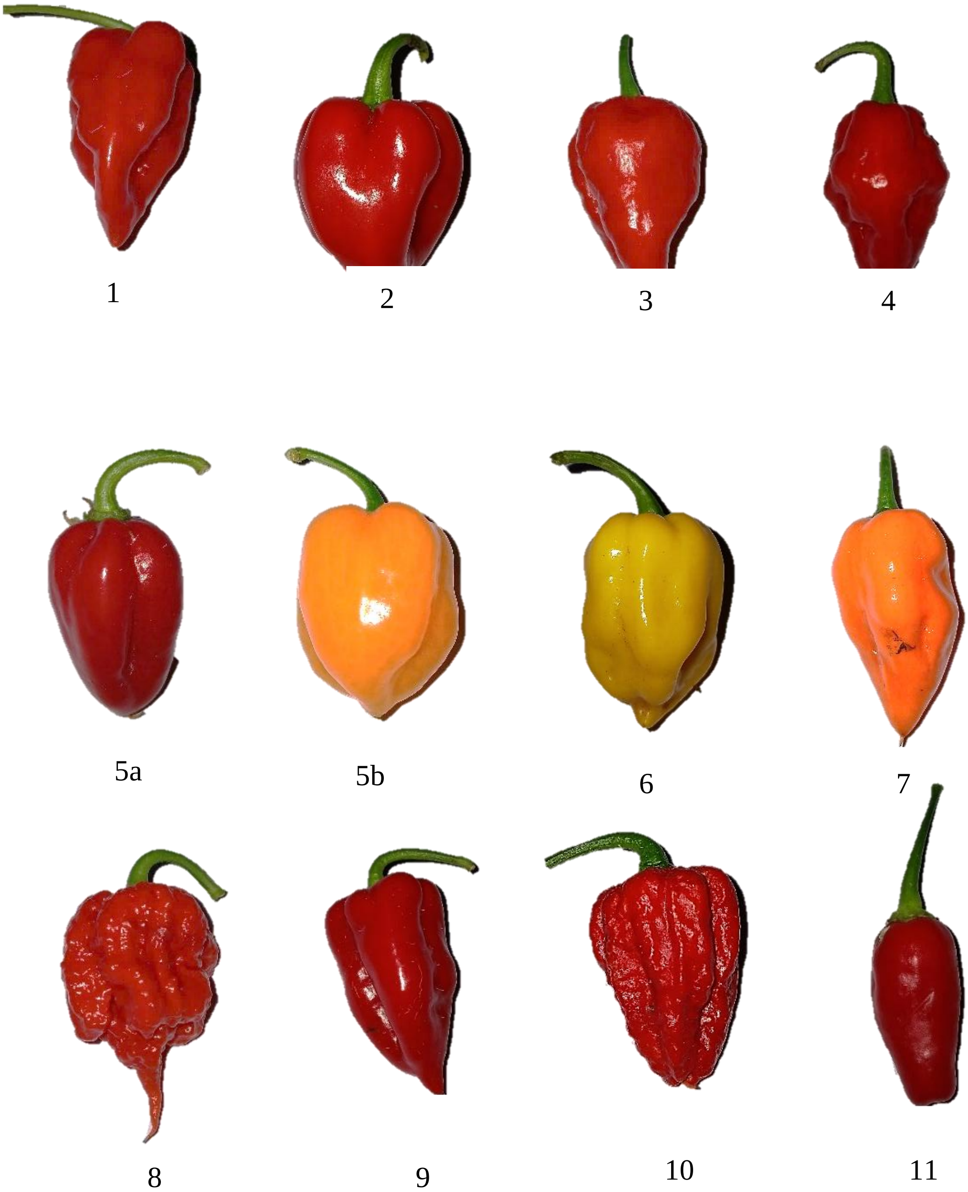

Figure 1. Color of Old Fruit In Some Super Spicy Chili Genotypes: 1) Genotype F1.383388; 2) F1.382383; 3) F1.383385; 4) F5.382383-5-12-3; 5a) F4.382385-5-2; 5b) F4.382385-5-2 6) F4.382385-4-1; 7) F6.382384-4-1-8-1; 8) Carolina Reaper; 9) Katokkon; 10) Red Bhut Jolokia; 11) Mhanu.

The number of fruits per plant indicates reproductive capacity, often showing a trade-off with fruit weight due to limited photosynthate distribution (Abdul-Rafiu et al., 2019). Fruit weight per plant integrates both components and represents overall productivity. Genotypes with higher fruit weight per plant have the potential to enhance crop productivity and production efficiency, thereby increasing the economic returns for farmers. The superior performance of F5.382383-5-12-3 in fruit number and total yield, combined with F1.383385's excellence in fruit weight and

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quality, demonstrates that different genotypes may excel in different yield components. For developing high-yielding superior varieties, F5.382383-5-12-3 is the best candidate for productivity, while F1.383385 offers balanced yield and quality.

Table 2. Fruit Base Shape, Seed Color, Fruit Gloss, Fruit Stalk Color, Color Placenta, and Flowering Age (dap) in Some Super Spicy Chili Genotypes

Genotype	Fruit Base	Seed Color	Fruit Gloss	Fruit Stalk Color	Color Placenta	Flowering Age (dap)
F1.383388	3.70 ± 0.14[abc]	2.85 ± 0.26[a]	6.74 ± 0.23[a]	2.22 ± 0.10[abcd]	4.00 ± 0.00[ab]	51.33 ± 2.31[bcde]
F1.382383	4.31 ± 0.57[ab]	3.00 ± 0.00[a]	6.78 ± 0.38[a]	1.94 ± 0.10[d]	4.17 ± 0.29[a]	45.00 ± 5.00[de]
F1.383385	3.33 ± 1.15[bc]	2.33 ± 1.15[a]	7.00 ± 0.00[a]	2.33 ± 0.58[abcd]	3.67 ± 0.58[abc]	55.33 ± 5.51[abc]
F5.382383-5-12-3	3.31 ± 0.13[bc]	2.83 ± 0.00[a]	6.83 ± 0.17[a]	2.08 ± 0.08[cd]	4.08 ± 0.08[a]	46.67 ± 2.89[cde]
F4.382385-5-2	3.56 ± 0.17[abc]	2.61 ± 0.35[a]	6.83 ± 0.00[a]	2.11 ± 0.05[bcd]	3.36 ± 0.13[bcd]	48.33 ± 2.89[cde]
F4.382385-4-1	3.72 ± 0.05[abc]	1.00 ± 0.00[b]	6.89 ± 0.10[a]	1.86 ± 0.27[d]	2.75 ± 0.08[d]	43.33 ± 2.89[e]
F6.382384-4-1-8-1	3.08 ± 0.08[cd]	2.61 ± 0.25[a]	6.83 ± 0.17[a]	2.70 ± 0.25[abc]	3.08 ± 0.36[cd]	46.67 ± 5.77[cde]
Carolina Reaper	4.67 ± 0.14[a]	3.00 ± 0.00[a]	6.78 ± 0.25[a]	2.75 ± 0.14[a]	4.00 ± 0.00[ab]	60.67 ± 2.52[ab]
Katokkon	3.39 ± 0.21[bc]	3.00 ± 0.00[a]	6.67 ± 0.17[a]	1.86 ± 0.05[d]	4.00 ± 0.00[ab]	53.33 ± 3.06[abcd]
Red Bhut Jolokia	3.63 ± 0.33[abc]	2.89 ± 0.19[a]	4.17 ± 0.14[b]	2.73 ± 0.10[ab]	3.92 ± 0.14[ab]	52.67 ± 2.31[abcde]
Mhanu	2.00 ± 0.00[d]	3.00 ± 0.00[a]	6.48 ± 0.13[a]	2.60 ± 0.17[abc]	4.00 ± 0.00[ab]	62.33 ± 4.04[a]
HSD 5%	1.22	1.13	0.55	0.64	0.70	9.84

Note: Numbers followed by the same letter in the same column are not significantly different from the 5% HSD test.

Table 4 presents fruit dimensional characteristics. Mhanu had the highest 1000 seed weight (5.30 g), significantly different from most genotypes, indicating superior seed filling and quality (Aboelkassem et al., 2021; Navaneetha et al., 2019). However, Mhanu's low fruit yield limits its commercial potential despite excellent seed characteristics. Fruit length was highest in F1.383385 (7.07 cm), while Red Bhut Jolokia and Mhanu had the lowest. Fruit stalk length was highest in F1.383388 (4.28 cm). Fruit diameter peaked in F1.383385 (33.96 mm), while Mhanu had the lowest (18.78 mm). Pulp thickness was highest in F4.382385-5-2, F6.382384-4-1-8-1, and F5.382383-5-12-3, while Red Bhut Jolokia had the lowest. Placenta length was highest in F1.383385 (6.50 cm), while Red Bhut Jolokia and Mhanu had the lowest. Fruit length and diameter are key indicators of fruit size, positively correlated with fruit weight and yield (Kumar & Singh, 2018; Singh et al., 2024). Pulp thickness improves consumption quality, shelf life, and resistance to post-harvest damage (Sowmya et al., 2023). Placenta length is an important fruit trait because the placenta is the primary site of capsaicin synthesis.

Regarding physiological traits (Table 5), leaf chlorophyll content was highest in Mhanu (55.09 units), followed by

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F6.382384-4-1-8-1 (53.58) and Red Bhut Jolokia (52.47), while Katokkon had the lowest (46.29). Leaf nitrogen content ranged from 2.03% to 4.48% across the evaluated genotypes. Descriptively, F4.382385-4-1 (4.48%) and F6.382384-4-1-8-1 (4.43%), showed the highest nitrogen contents, whereas F1.383385 had the lowest value (2.03%). Leaf Phosphorus content ranged from 0.03% to 0.32%, with Carolina Reaper showing the highest value (0.32%) and F1.383385 the lowest (0.03%). Leaf Potassium content ranged from 0.39% to 0.46%, with Carolina Reaper showing the highest value (0.46%) and F6.382384-4-1-8-1 the lowest (0.39%). descriptively, F4.382385-4-1 (4.83%) and F1.383385 (4.68%) showed relatively higher values, whereas F1.383388 and F1.382383 had lower values (2.90%). Chlorophyll content is widely recognized as an important indicator of photosynthetic capacity and is closely associated with nitrogen, a major constituent of chlorophyll molecules (Varga et al., 2025). In addition, nitrogen, phosphorus, and potassium play essential roles in chlorophyll synthesis, energy transfer, assimilate transport, and enzyme activation (El-Mogy et al., 2019; Xie et al., 2022; Xu & Mou, 2016). Therefore, relatively high levels of leaf nutrients, total sugar, and chlorophyll may reflect favorable physiological conditions for plant growth.

Table 3. Harvest Age (dap), Weight per Fruit (g), Number of Fruits per Plant (fruit plant^{-1}), Fruit Weight per Plant (g plant^{-1}), and Weight 1000 (g) Seeds in Some Super Spicy Chili Genotypes

Genotype	Harvest Age (dap)	Weight per Fruit (g)	Number of Fruits per Plant (fruit plant^{-1})	Fruit Weight per Plant (g plant $^{-1}$)	Weight 1000 Seeds (g)
F1.383388	126.00 ± 5.20^{bc}	10.22 ± 0.76^{ab}	112.82 ± 4.19^{ab}	811.41 ± 81.77^{abc}	4.37 ± 0.13^{b}
F1.382383	126.00 ± 5.20^{bc}	10.67 ± 2.03^{ab}	96.22 ± 4.19^{abc}	753.66 ± 120.28^{abc}	4.46 ± 0.13^{b}
F1.383385	132.67 ± 17.01^{abc}	13.84 ± 7.71^{a}	125.33 ± 15.97^{ab}	1,095.53 ± 719.95^{ab}	4.79 ± 0.47^{ab}
F5.382383-5-12-3	112.00 ± 6.93^{c}	12.67 ± 1.04^{a}	151.11 ± 84.95^{a}	1,268.00 ± 168.26^{a}	4.44 ± 0.15^{b}
F4.382385-5-2	123.00 ± 5.20^{bc}	10.54 ± 0.55^{ab}	100.81 ± 8.01^{abc}	696.06 ± 27.34^{abc}	4.50 ± 0.20^{b}
F4.382385-4-1	123.00 ± 5.20^{bc}	9.83 ± 1.09^{ab}	130.78 ± 8.00^{ab}	865.37 ± 86.28^{abc}	4.57 ± 0.31^{b}
F6.382384-4-1-8-1	126.00 ± 5.20^{bc}	10.90 ± 0.68^{ab}	130.14 ± 10.80^{ab}	872.02 ± 62.82^{abc}	4.40 ± 0.02^{b}
Carolina Reaper	137.33 ± 7.37^{ab}	9.10 ± 0.48^{ab}	28.75 ± 13.49^{c}	182.27 ± 17.66^{c}	4.68 ± 0.20^{ab}
Katokkon	126.00 ± 5.20^{bc}	12.54 ± 1.47^{a}	65.81 ± 1.89^{bc}	562.27 ± 71.51^{bc}	4.43 ± 0.17^{b}
Red Bhut Jolokia	140.67 ± 10.69^{ab}	5.34 ± 0.90^{b}	60.92 ± 7.63^{bc}	300.71 ± 123.18^{c}	4.54 ± 0.20^{b}
Mhanu	152.00 ± 11.53^{a}	4.85 ± 1.15^{b}	98.46 ± 26.01^{abc}	375.15 ± 49.60^{c}	5.30 ± 0.10^{a}
HSD 5%	24.73	6.91	81.29	699.35	0.68

Note: Numbers followed by the same letter in the same column are not significantly different from the 5% HSD test.

In this study, descriptive observations indicated that Mhanu and Carolina Reaper exhibited relatively high chlorophyll and nutrient contents but comparatively low fruit yields. This pattern may indicate that relatively high source capacity alone is not always associated with high productivity and could be associated with differences in assimilate allocation from source (leaves) to sink (fruits). Likewise, when fruit number is limited, overall yield may remain relatively low despite high photosynthetic capacity. Therefore, plant productivity may depend not only on the capacity to produce photosynthates but also on their allocation and utilization by

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developing fruits. In contrast, F1.383385 and F5.382383-5-12-3 produced relatively high fruit yield and quality, which may reflect more effective utilization of photosynthetic products. However, because leaf nutrient contents and total leaf sugar were analyzed descriptively without inferential statistical analysis, these observations should be interpreted with caution and should not be regarded as statistically validated evidence of assimilate partitioning or translocation. Further physiological studies involving direct measurements of photosynthesis, assimilate partitioning, and sink strength are required to confirm these relationships.

Table 4. Fruit Length (cm), Fruit Stalk Length (cm), Fruit Diameter (mm), Pulp Thickness (mm), and Placenta Length (cm) in Some Super Spicy Chili Genotypes

Genotype	Fruit Length (cm)	Fruit Stalk Length (cm)	Fruit Diameter (mm)	Pulp Thickness (mm)	Placenta Length (cm)
F1.383388	5.61 ± 0.29[ab]	4.28 ± 0.41[a]	27.64 ± 1.05[b]	1.76 ± 0.10[bcd]	5.26 ± 0.30[ab]
F1.382383	4.55 ± 0.09[ab]	3.15 ± 0.24[b]	29.18 ± 3.83[ab]	1.91 ± 0.08[abc]	4.31 ± 0.30[ab]
F1.383385	7.07 ± 2.98[a]	3.03 ± 0.85[b]	33.96 ± 5.28[a]	1.77 ± 0.22[bcd]	6.50 ± 2.78[a]
F5.382383-5-12-3	6.04 ± 0.27[ab]	3.65 ± 0.11[ab]	29.01 ± 2.05[ab]	2.20 ± 0.01[a]	5.67 ± 0.26[ab]
F4.382385-5-2	4.58 ± 0.27[ab]	3.42 ± 0.04[ab]	25.87 ± 0.15[b]	2.23 ± 0.12[a]	4.17 ± 0.24[ab]
F4.382385-4-1	5.28 ± 0.01[ab]	3.02 ± 0.11[b]	27.33 ± 2.25[b]	1.78 ± 0.05[bcd]	4.86 ± 0.17[ab]
F6.382384-4-1-8-1	5.55 ± 0.08[ab]	3.70 ± 0.08[ab]	26.10 ± 1.56[b]	2.24 ± 0.19[a]	5.07 ± 0.21[ab]
Carolina Reaper	4.66 ± 0.28[ab]	3.44 ± 0.09[ab]	29.48 ± 0.15[ab]	1.54 ± 0.05[cd]	4.19 ± 0.37[ab]
Katokkon	5.45 ± 0.35[ab]	3.59 ± 0.05[ab]	28.33 ± 1.41[ab]	2.11 ± 0.17[ab]	5.02 ± 0.28[ab]
Red Bhut Jolokia	3.70± 0.54[b]	3.61 ± 0.24[ab]	26.57 ± 1.18[b]	1.48 ± 0.03[d]	3.29 ± 0.46[b]
Mhanu	3.84 ± 0.19[b]	3.50 ± 0.45[ab]	18.78 ± 4.17[c]	1.68 ± 0.12[cd]	3.52 ± 0.16[b]
HSD 5%	2.69	0.99	6.21	0.38	2.62

Note: Numbers followed by the same letter in the same column are not significantly different from the 5% HSD test.

Based on the comprehensive evaluation of yield and quality traits, two genotypes emerged as superior candidates for developing high-yielding and high-quality varieties. Genotype F5.382383-5-12-3 showed the highest fruit weight per plant (1,268.00 g plant^{-1}) and number of fruits per plant (151.11 fruit plant^{-1}), combined with early harvest age (112.00 dap), making it the best candidate for developing high-yielding superior varieties targeting maximum productivity. Genotypes F5.382383-5-12-3 may be associated with their ability to maintain a high number of fruits and fruit weight throughout the growing period. However, the physiological mechanisms underlying this performance were not directly evaluated in the present study. The greater fruit weight may also be associated with enhanced cell division and cell expansion during fruit development, although this requires further physiological confirmation. Chili yield improvement depends not only on fruit size but also on the plant's ability to produce an optimal number of fruits, leading to increased fruit length and larger fruit diameter (Chernet & Zibelo, 2019; Gonzalez-Lopez et al., 2021).

Genotype F1.383385 demonstrated superior quality traits, including the highest fruit length (7.07 cm), fruit diameter (33.96 mm), placenta length (6.50 cm), fruit shape score (7.67), and weight per fruit (13.84 g), combined with strong yield performance (1,095.53 g plant^{-1}), making it the best candidate for developing high-quality, superior varieties targeting premium markets. Placenta length is an important fruit trait in

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Capsicum because the placenta is the primary site of capsaicinoid biosynthesis. In the present study, genotypes with longer placentas generally exhibited favorable fruit quality characteristics. However, capsaicinoid content was not measured; therefore, the relationship between placenta length and capsaicinoid accumulation was not experimentally validated in this study and should be interpreted with caution. Although previous studies have reported that placenta development is positively associated with capsaicinoid accumulation because most capsaicinoids are synthesized and stored in placental tissues (Tanaka, 2025; Uarrota et al., 2021), the present results do not confirm that placenta length is a validated indirect selection criterion for pungency. Direct quantification of capsaicinoids is required to verify this relationship in future studies. Considering both yield and fruit quality, F1.383385 exhibited a favorable combination of agronomic performance and fruit quality traits, whereas F5.382383-5-12-3 showed outstanding yield performance. Therefore, genotype selection should be aligned with the breeding objective, whether prioritizing fruit quality, yield, or a combination of both.

Table 5. Leaf Chlorophyll Content (Unit), Nutrient Content N, P, K Leaves (%), and Total Sugar Content of Leaves (%) in Several Super Spicy Chili Genotypes

Genotype	Leaf Chlorophyll Content (Unit)	N Nutrient Content of Leaves (%)	P Nutrient Content of Leaves (%)	K Nutrient Content of Leaves (%)	Total Sugar Content of Leaves (%)
F1.383388	48.00 ± 1.34[cde]	3.150	0.260	0.430	2.90
F1.382383	47.39 ± 1.06[de]	4.200	0.190	0.440	2.90
F1.383385	46.52 ± 5.29[e]	2.030	0.030	0.420	4.68
F5.382383-5-12-3	50.60 ± 1.69[abcde]	3.850	0.180	0.410	3.20
F4.382385-5-2	48.68 ± 1.79[bcde]	3.920	0.180	0.420	3.50
F4.382385-4-1	53.16 ± 0.11[abc]	4.480	0.140	0.400	4.83
F6.382384-4-1-8-1	53.58 ± 1.25[ab]	4.430	0.130	0.390	4.21
Carolina Reaper	49.38 ± 1.37[bcde]	4.410	0.320	0.460	3.08
Katokkon	46.29 ± 1.95[e]	3.710	0.150	0.410	3.12
Red Bhut Jolokia	52.47 ± 1.38[abcd]	4.130	0.160	0.410	4.20
Mhanu	55.09 ± 0.56[a]	3.150	0.180	0.420	3.41
HSD 5%	5.56	-	-	-	-

Note: Numbers followed by the same letter in the same column are not significantly different from the 5% HSD test, and the sign (-) indicates that the data was not analyzed.

The results demonstrated positive relationships between yield and fruit quality traits among the evaluated super-hot chili genotypes. Fruit weight per plant was positively correlated with placenta length (r = 0.821), fruit length (r = 0.794), fruit weight (r = 0.736), fruit glossiness (r = 0.495), and fruit diameter (r = 0.439), indicating that higher-yielding genotypes also tended to produce superior fruit quality (Prasad et al., 2025; Baruah et al., 2023). Among these traits, placenta length showed the strongest correlation with yield, suggesting its important role in fruit development and assimilate accumulation. Positive correlations with fruit length and fruit weight further indicate that higher yield was associated with both increased fruit number and improved fruit size. Fruit diameter and glossiness also contributed positively to yield, although their relationships were weaker. These traits remain important because they influence fruit appearance and market value. Genotype F5.382383-5-12-3 exhibited the highest yield, whereas F1.383385 combined relatively high yield with superior fruit quality, demonstrating distinct breeding advantages. These

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relationships may be associated with source–sink dynamics, as suggested by previous studies (Tsan et al., 2024; Heuvelink et al., 2025). However, because physiological traits such as photosynthetic rate, assimilate partitioning, and sink strength were not directly measured in the present study, this explanation should be interpreted with caution.

Yield and fruit quality are the primary targets of chili breeding because they determine crop productivity, market acceptance, and economic value. Therefore, superior genotypes should combine high yield with desirable fruit quality traits to meet the requirements of producers, consumers, and the food industry. Simultaneous evaluation of these traits improves breeding efficiency and facilitates the development of cultivars with broad commercial potential (FAO, 2023).

4. Limitations and Future Directions

This study has several limitations that should be addressed in future research. First, the research was conducted under greenhouse conditions at only one altitude (Bedugul, Bali, ±1200 m asl), so the stability of genotype performance across different environments remains unknown. Consequently, genotypes that exhibited superior performance in this study may not necessarily perform similarly under different locations or growing seasons. Nevertheless, the use of a Randomized Complete Block Design (RCBD) helped minimize environmental variation within the experimental site by grouping experimental units with relatively homogeneous conditions. As a result, the observed differences among genotypes were more likely attributable to genetic factors rather than environmental variation within the experimental site. Second, quality assessment was limited to morphological parameters and did not directly measure capsaicin content using HPLC or spectrophotometry, which is the primary quality attribute for super-hot chili. Third, the number of genotypes tested was limited to seven promising lines plus four comparators, and pest-disease resistance was not evaluated.

Based on these limitations, the following suggestions are proposed for future research. Multi-season and open field trials should be conducted to evaluate yield stability and adaptability across different agroecosystems before variety release. Quantitative analysis of capsaicin content using HPLC or spectrophotometry is essential to directly measure pungency levels, which is the most critical quality trait for super-hot chili varieties. Evaluation of resistance to major pests and diseases, as well as input use efficiency, should be included to ensure the developed varieties are suitable for sustainable cultivation. Finally, advanced yield trials and adaptation tests are necessary as the next steps toward official variety release.

5. Conclusion

The evaluation of seven promising super-hot chili genotypes revealed significant genetic variability for all yield and quality components, confirming that genotype selection is essential for developing high-yielding and high-quality superior varieties. Genotype F5.382383-5-12-3 demonstrated the highest productivity with 1,268.00 g plant^{-1} fruit weight per plant and 151.11 fruits plant^{-1}, combined with early harvest age (112.00 dap), these findings indicate that this genotype has strong potential for development as a high-yielding super-hot chili cultivar. In contrast, genotype F1.383385 exhibited superior fruit quality, characterized by the highest fruit weight (13.84 g), fruit length (7.07 cm), fruit diameter (33.96 mm), and placenta length (6.50 cm), together with a mature red fruit color comparable to the commercial check cultivars (score = 4.00) and the highest fruit glossiness (strong gloss; score = 7.00). Correlation analysis further revealed positive relationships between fruit weight per plant with several fruit quality traits, including placenta length, fruit glossiness, fruit weight,

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fruit length, and fruit diameter, indicating that genotypes with higher yield also tended to produce fruits with superior quality attributes. These findings provide valuable information for selecting superior *Capsicum chinense* genotypes and support their utilization in breeding programs aimed at developing high-yielding and high-quality super-hot chili cultivars.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the authors used ChatGPT to proofread and Deepl to translate Indonesian into English. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Authorship Contribution Statement

1) Ni Putu Ayu Arini: Conducting a literature studies, collecting data, analyzing data and conducting experiments/surveys (hands-on research), making the first draft of journal articles (abstracts, introductions, methods, results, and discussions), revising drafts based on input from other supervisors/authors; 2) I Nyoman Rai: Conceptualization, methodology, getting research cooperation, guiding, directing, reviewing all manuscript contents to ensure scientific quality, and act as a Corresponding Author who deals with journal editors; 3) Ni Nyoman Ari Mayadewi: Assist in writing certain parts of the article, provide input, revision, and constructive criticism of the draft article, ensure that the methodology and results presented are appropriate; 4) Muhamad Syukur: Conceptualization, Methodology, obtaining research funding and providing facilities, guiding during the research process; 5) Arya Yuda Pangestu: provide facilities, help direct and guide in the research process, and ensure the correctness of the results of data analysis; Orlince Mamakani: Conducting a literature studies.

Declaration of Competing Interest

The authors declare there is no conflict of interest.

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