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PERFORMANCE EVALUATION OF *CAPSICUM ANNUUM* L. GENOTYPES FOR GROWTH, PHENOLOGICAL AND PROCESSING-RELATED TRAITS UNDER A COCONUT ECOSYSTEM

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ABSTRACT
Capsicum annuum L. is an economically important spice crop valued for its processing quality, natural pigments and industrial applications. However, genotype performance varies considerably across production environments, necessitating the evaluation of diverse genetic resources under specific production systems. Although coconut-based production systems provide opportunities for crop diversification and efficient resource utilization, information on the performance of *Capsicum annuum* L. genotypes under the modified microclimatic conditions of coconut ecosystems remains limited. Therefore, the present study evaluated twenty-five *Capsicum annuum* L. genotypes for growth, phenological and fruit morphological traits to identify promising genotypes for cultivation under a coconut ecosystem. The experiment was conducted during June to November at the Department of Spices and Plantation Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, following a Randomized Block Design with three replications. Observations were recorded on thirteen quantitative traits related to vegetative growth, phenology and fruit morphology. Significant variation was observed among the genotypes for all the traits studied. CAG-12 exhibited superior vegetative growth, whereas CAG-17 was the earliest for flowering and ripening. CAG-4 produced the longest fruits, while CAG-5 recorded the highest pericarp thickness and 1000-seed weight. CAG-8 combined desirable fruit length, fruit diameter and pericarp thickness, indicating its potential for processing. Overall, CAG-8, CAG-5, CAG-4 and CAG-12 emerged as promising genotypes for cultivation under a coconut ecosystem. The findings provide baseline information for genotype selection and support crop diversification in coconut-based production systems.

KEYWORDS: *Capsicum annuum*; Coconut ecosystem; Fruit morphology; Genotype evaluation; Intercropping; Phenology

1. INTRODUCTION
Capsicum annuum L. is an economically important spice crop cultivated worldwide for its characteristic red colour, distinctive flavour and nutritional value. Besides its extensive culinary use, it is recognized as a rich source of natural carotenoids, particularly capsanthin and capsorubin, along with vitamins, phenolic compounds and antioxidants that contribute to its nutritional and functional properties. The increasing demand for natural food ingredients has further enhanced the importance of *Capsicum annuum* L. in the food, nutraceutical and processing industries. Its fruits are widely utilized for the production of paprika powder, natural colourants, oleoresins and other value-added products owing to their high carotenoid content (Ferrando *et al.,* 2024; Hernández-Pérez *et al*., 2020; Rodriguez-Amaya *et al*., 2023). Since the commercial value of *Capsicum annuum* L. cultivated for paprika production largely depends on fruit quality attributes such as fruit size, shape, colour intensity and processing suitability, the identification of superior genotypes is essential for sustainable production and industrial utilization (Park *et al*., 2021).
Substantial variation exists among *Capsicum annuum* L. genotypes for vegetative growth, phenological behaviour, fruit morphology and processing-related traits. Such variability provides opportunities for selecting superior genotypes with improved adaptation, productivity and industrial value. Evaluation of growth characteristics, flowering and maturity behaviour, and fruit morphological traits is important for selecting genotypes with better adaptation, productivity and processing potential. Previous studies have reported significant variation among paprika and chilli genotypes for plant architecture, flowering time, fruit size, pericarp thickness and seed characteristics, emphasizing the importance of systematic genotype evaluation before commercial cultivation (Belay *et al*., 2020; McLeod *et al*., 2023; Ratna *et al*., 2024). Fruit morphological traits such as fruit length, fruit diameter, pericarp thickness and seed recovery are particularly important for the processing industry because they directly influence drying efficiency, pigment recovery and overall product quality (Karataş and

Büyükdinç, 2024). Therefore, comprehensive evaluation of diverse *Capsicum annuum* L. germplasm provides valuable information for identifying promising genotypes suitable for specific production systems and industrial applications.

Coconut-based cropping systems provide an effective approach for crop diversification and efficient utilization of available resources. In conventional coconut plantations, only a portion of the available land area, canopy space and incident solar radiation is effectively utilized, leaving substantial interspaces suitable for cultivating compatible intercrops (Nuwarapaksha *et al*., 2022). Integration of horticultural crops into coconut plantations has been shown to improve land-use efficiency, cropping intensity, farm income and overall system sustainability without adversely affecting coconut productivity (Francis *et al*., 2024). Several studies have also demonstrated that vegetable cultivation under coconut ecosystems enhances productivity, profitability, soil health and resource-use efficiency, thereby contributing to the sustainability of coconut-based farming systems (Maheswarappa and Basavaraju, 2017; Khopade *et al*., 2025; Rani *et al*., 2024). However, information on the performance of *Capsicum annuum* L. genotypes under coconut ecosystems remains limited. In particular, systematic evaluation of growth, phenological behaviour and fruit morphological traits under the modified microclimatic conditions prevailing beneath coconut canopies has received little attention.

Therefore, the present study was undertaken to evaluate twenty-five *Capsicum annuum* L. genotypes for growth, phenological and fruit morphological traits under a coconut ecosystem. The objective was to identify promising genotypes with superior adaptation and desirable fruit characteristics suitable for cultivation in coconut-based production systems, thereby providing baseline information for genotype selection and promoting diversification of coconut-based farming systems.

2. MATERIALS AND METHODS

2.1. Experimental Site

The field experiment was conducted at the Department of Spices and Plantation Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural University (TNAU), Coimbatore, India, during the kharif season (June to November). The experimental site is located at 11.010° N latitude, 76.930° E longitude, at an altitude of 426 m above mean sea level (MSL). The study was carried out under an established coconut-based production system.

2.2. Plant Materials

Twenty-five *Capsicum annuum* L. genotypes (CAG-1 to CAG-25) collected from the major *Capsicum annuum* L. growing regions of Tamil Nadu, Karnataka, Telangana, Maharashtra, Andhra Pradesh, Kerala, Gujarat and Rajasthan were used in the study. The diverse geographical origin of the genotypes provided a broad range of variation for evaluating growth, phenological and fruit morphological traits under the coconut ecosystem.

2.3. Experimental Design and Crop Management

The experiment was laid out in Randomized Block Design (RBD) three replications. Seedlings of *Capsicum annuum* L. were transplanted at spacing of 60 × 45 cm and grown under the coconut ecosystem. All the agronomic practices recommended such as irrigation, nutrient management, intercultural operations and plant protection, were strictly adhered to during the growing period of the crop as per TNAU guidelines.

2.4 Recording of Observations

Observations on thirteen quantitative traits representing vegetative growth, phenological development and fruit morphology were recorded from five randomly selected and tagged plants in each replication. Growth parameters measured were plant height (cm), plant spread (cm), leaf length (cm) and leaf width (cm). Phenological observations were made as days to 50% flowering and days to 50% ripening. The fruit morphological and processing related characteristics were fruit length (cm), fruit diameter (cm), pericarp thickness (mm), fruit stalk length (cm), 1000-seed weight (g), seed recovery (%), and number of locules per fruit.

2.5 Statistical Analysis

IBM SPSS Statistics version 22.0 (IBM Corp., Armonk, NY, USA) was used for analysis of variance (ANOVA) which is appropriate for a Randomized Block Design (RBD). The Critical Difference (CD) test was used to compare treatment means at 5% level of significance ($P \leq 0.05$). To assess the precision and reliability of the experiments, standard error of mean [SE(m)], standard error of difference [SE(d)], and coefficient of variation (CV) were calculated.

3. RESULTS AND DISCUSSION

3.1 Growth performance of *Capsicum annuum* L. genotypes under coconut ecosystem

Significant variation was observed among the twenty-five *Capsicum annuum* L.genotypes for vegetative growth traits under the coconut ecosystem (Table 1), which reflected differences in plant vigour and canopy development in the coconut ecosystem. Plant height ranged from 67.2 cm in CAG-17 to 127.4 cm in CAG-12, with a mean of 97.52 cm, while plant spread varied from 52.5 cm in CAG-17 to 76.0 cm in CAG-12, averaging 65.77 cm. Leaf length ranged from 5.7 cm in CAG-17 to 9.5 cm in CAG-12, whereas leaf width varied from 3.4 cm in CAG-17 to 5.6 cm in CAG-12. Among the evaluated genotypes, CAG-12 recorded the highest plant height, plant spread, leaf length and leaf width, indicating superior vegetative vigour, whereas CAG-17, CAG-7 and CAG-16 exhibited comparatively compact plant growth. Figure 2 illustrates the variation in plant architecture and vegetative growth among representative *Capsicum annuum* L. genotypes grown under a coconut ecosystem. Vegetative growth also showed genotype dependent variation in Capsicum, where significant difference in the vegetative growth parameters of plant height, canopy spread and leaf characteristics were observed between the different production environments of the genotypes evaluated (Anani *et al*., 2024; Ratna *et al*., 2024). Measurements of plant height, plant spread, leaf length and leaf width have relatively low coefficients of variation (3.15-3.19%), which means that there is good experimental precision and stable expression of these traits across replications. The observed phenotypic variation provides valuable information for identifying vigorous genotypes adapted to cultivation under coconut-based production systems.

3.2 Phenological performance of *Capsicum annuum* L. genotypes under coconut ecosystem

There were significant differences in the evaluated *Capsicum annuum* L. genotypes for phenological characteristics under the coconut ecosystem (Table 2). Days to 50% flowering ranged from 73.3 days in CAG-17 to 92.2 days in CAG-12, with a mean of 81.70 days, whereas days to 50% ripening ranged from 102.2 days in CAG-17 to 126.3 days in CAG-12, averaging 113.43 days. CAG-17 and CAG-7 exhibited shorter crop duration while CAG-12, CAG-5, CAG-8, CAG-22 and CAG-23 had comparatively longer crop duration. The close association of early flowering with early ripening observed in the present work is in accordance with the earlier reported results in chilli wherein high genotype x environment interaction has been reported for crop duration (Sayekti *et al*., 2021; Sushmitha *et al*., 2024). Phenological traits are significant in the evaluation of varieties since they affect the duration of the crop, its harvesting schedule and production planning. Early-maturing genotypes would be desirable in areas where early harvest and several crops per year are desirable, while relatively late maturing ones would be selected in areas where a longer crop duration would be acceptable. The flowering and ripening traits had a relatively low coefficient of variation (3.14%) and hence the corresponding CD and SE values suggested stable expression of the traits from replications. The phenological assessment revealed that CAG-17 and CAG-7 were promising early-maturing genotypes, and the others, CAG-12, CAG-5, CAG-8, CAG-22 and CAG-23, were relatively late-maturing genotypes which would be suitable for longer duration production system.

3.3 Fruit morphological and processing-related traits of *Capsicum annuum* L. genotypes under coconut ecosystem

Considerable variation was observed among the *Capsicum annuum* L. genotypes for fruit morphological and processing-related traits, indicating substantial diversity in characteristics important for commercial cultivation and industrial processing (Table 3). The pericarp thickness varied from 1.5 mm in CAG-7 and CAG-17 to 3.6 mm in CAG-5 while fruit-stalk length varied from 1.2 cm in CAG-5 and CAG-12 to 2.7 cm in CAG-18. The thousand-seed weight ranged from 3.5 g to 6.6 g, seed recovery ranged from 26.8% to 56.1% and the number of locules ranged from 2.0 to 2.4. Figure 3 shows the variability of fruit length, fruit diameter and general fruit shape of typical *Capsicum annuum* L. genotypes. The same variation in fruit morphology was reported in germplasm of peppers, which indicates that fruit size and shape is important for varietal evaluation and processing purposes (Bhattarai *et al*., 2020; Ridzuan *et al*., 2019). The longest fruits were harvested from CAG-4 with a mean length of 15.5 cm while the comparatively larger fruit diameter (4.1 cm) was obtained from CAG-8 which produced 14.5 cm fruits. The CAG-5 had the maximum pericarp thickness (3.6 mm) and the highest thousand-seed weight (6.6 g) and the highest seed recovery (56.1%), whereas the CAG-3 had the highest seed recovery (55.2%) and comparatively thick pericarp. A thicker pericarp is considered a desirable trait because it contributes to greater dry matter accumulation, improved drying efficiency and enhanced suitability for processing into paprika products. Fruit stalk length, thousand-seed weight, seed recovery and number of locules were also observed as indicators of fruit structure and seed characteristics and showed variation among the evaluated genotypes. The whole fruit and processing traits were taken into account and CAG-8 CAG-4, CAG-5 and CAG-3 had desirable combinations. CAG-8 exhibited superior combination of long fruits, large fruit diameter and thick pericarp; CAG-4 had large fruit diameter, long fruits; CAG-5 had thick pericarp, thousand-seed weight and seed recovery; and CAG-3 had thick pericarp and comparatively high seed recovery. By contrast, CAG-7, CAG-17, CAG-23 and CAG-25 yielded relatively small fruits with thin pericarp and low seed recovery, suggesting their relatively low suitability for processing oriented cultivation based on the assessed traits. In general, the evaluation of fruit morphological and processing related traits showed high variation among *Capsicum annuum* L. genotypes grown in the coconut ecosystem. The fruit size, pericarp thickness and seed characteristics of all the cultivars CAG-8, CAG-4, CAG-5 and CAG-3 had favourable combinations, making them promising for commercial cultivation and processing applications. The results will serve as a practical guide for the screening of the *Capsicum annuum* L. genotypes for desirable fruit traits for production under coconut-based systems.

4. CONCLUSION

The present study revealed that there were significant differences between the twenty five *Capsicum annuum* L. genotypes with respect to vegetative growth, phenological behaviour and fruit morphological traits in coconut ecosystem. Such differences indicate the potential for identifying promising genotypes suitable for cultivation under coconut based production system. The genotype CAG-12 exhibited superior vegetative growth with maximum plant height (cm), plant spread (cm), leaf length (cm) and leaf width (cm) among the evaluated genotypes. CAG-17 had the lowest 50% flowering and 50% ripening time, whereas CAG-4 produced the longest fruits. CAG-5 had the highest pericarp thickness and 1000-seed weight while CAG-8 had high fruit length with high fruit diameter and pericarp thickness. On the whole, CAG-8, CAG-5, CAG-4 and CAG-12 proved to be the promising genotypes with respect to overall performance under coconut ecosystem. The results provide valuable baseline data for the selection of suitable *Capsicum annuum* L. genotypes for coconut based production systems. However, further multi-location and multi-season evaluations are required before these genotypes can be recommended for wider cultivation.

Ethics approval and consent to participate
This study did not involve human participants or experimental animals. Therefore, ethical approval and informed consent were not required.

Conflict of Interest
The authors declare that they have no competing interests.

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Author Contributions
Shalini K. - Designing of the experiment, conduct of field experiment, data collection, statistical analysis, interpretation of results and preparation of the manuscript. **Aneesa Rani M.S.** - Conceptualization, designing of the experiment, supervision, interpretation of results and critical revision of the manuscript. **Mohanalakshmi M.** - Data analysis, validation of results and manuscript review. **Kalaiyarasi R.** - Methodology, data interpretation and manuscript review. **Amirtham D.** - Technical guidance, validation of the study and manuscript review. **Bharathi N.** - Interpretation of results, manuscript review, editing and overall supervision.

Availability of data
The whole data relevant to the experiments are included in this paper.

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Table 1. Growth performance of *Capsicum annuum* L. genotypes cultivated under a coconut ecosystem.

Genotypes	Plant Height (cm)	Plant Spread (cm)	Leaf Length (cm)	Leaf Width (cm)
CAG-1	88.2	62	6.5	3.8
CAG-2	77	58.5	6	3.5
CAG-3	111	72.5	8.5	5.2
CAG-4	102.2	68	6.8	4.2
CAG-5	124.6	75	9.2	5.5
CAG-6	95.2	65.5	6.4	3.9
CAG-7	72.8	55	5.8	3.6
CAG-8	119.6	74	8.8	5.3
CAG-9	105	69.5	6.9	4.1
CAG-10	95.9	66	6.6	3.9
CAG-11	98.3	67.2	6.7	4
CAG-12	127.4	76	9.5	5.6
CAG-13	96.6	66.8	6.5	4.2
CAG-14	83.2	60.5	6.2	3.7
CAG-15	81.5	59.8	6.1	3.6
CAG-16	75.6	57	5.9	3.5
CAG-17	67.2	52.5	5.7	3.4
CAG-18	95.2	65.5	7.2	4.3
CAG-19	116.2	71	6.9	4.1
CAG-20	81.2	60	6.3	3.8
CAG-21	117.5	72	6.8	4
CAG-22	107.8	70	8.7	4.6
CAG-23	122.2	74.5	6.7	4
CAG-24	80.9	59.5	6.2	3.7
CAG-25	95.9	66	6.6	3.9
Mean	97.52	65.77	6.94	4.13
CD (P = 0.05)	5.11	3.42	0.36	0.21
SE(m)	1.79	1.20	0.13	0.08
SE(d)	2.54	1.70	0.18	0.11
CV (%)	3.19	3.16	3.19	3.15

Table 2. Phenological performance of *Capsicum annuum* L. genotypes cultivated under a coconut ecosystem

Genotypes	Days to 50% flowering	Days to 50% ripening
CAG-1	78.2	108.2
CAG-2	75.3	105.4

CAG-3	88.1	122.3
CAG-4	82.4	115.2
CAG-5	90.2	124.1
CAG-6	80.3	110.3
CAG-7	74.1	103.5
CAG-8	89.2	123.2
CAG-9	83.4	116.4
CAG-10	80.1	110.1
CAG-11	81.3	111.2
CAG-12	92.2	126.3
CAG-13	82.1	114.2
CAG-14	77.4	107.3
CAG-15	76.2	106.1
CAG-16	75.1	105.4
CAG-17	73.3	102.2
CAG-18	84.2	118.3
CAG-19	85.3	119.2
CAG-20	77.1	107.5
CAG-21	86.4	120.4
CAG-22	87.2	121.3
CAG-23	86.1	120.2
CAG-24	77.3	107.2
CAG-25	80.2	110.3
Mean	81.70	113.43
CD (P = 0.05)	4.23	5.87
SE(m)	1.48	2.06
SE(d)	2.10	2.91
CV (%)	3.14	3.14

Table 3. Fruit morphological and processing-related traits of *Capsicum annuum* L. genotypes cultivated under a coconut ecosystem

Genotypes	**Fruit length (cm)**	**Fruit diameter (cm)**	**Pericarp thickness (mm)**	**Fruit stalk length (cm)**	**1000 seed weight (g)**	**Seed recovery (%)**	**Number of locules**
CAG-1	9.5	2.4	1.6	1.6	3.6	28.4	2
CAG-2	12.3	2.9	1.7	1.7	3.7	27.9	2.1
CAG-3	12.6	2.6	3.4	1.3	6.4	55.2	2.3
CAG-4	15.5	2.3	2.5	1.9	4.8	36.3	2.2
CAG-5	6.8	2.6	3.6	1.2	6.6	56.1	2.3
CAG-6	12.4	2.5	1.9	1.8	3.9	29.1	2.1
CAG-7	9.4	2.2	1.5	1.7	3.5	26.8	2
CAG-8	14.5	4.1	3.5	1.3	6.5	38.5	2.4
CAG-9	10.7	2.8	2.3	1.9	4.6	34.2	2.2
CAG-10	12.8	1.3	1.8	1.8	3.8	28.7	2
CAG-11	6.6	2.2	1.9	1.9	3.9	29.3	2.1
CAG-12	7.6	3.4	2.8	1.2	5.2	39.1	2.3
CAG-13	9.9	3.8	2.6	2.6	5.1	37.4	2.2
CAG-14	11.6	4.2	1.7	1.7	3.7	28.1	2.1
CAG-15	7.3	2.9	1.8	1.6	3.8	28.6	2.1
CAG-16	10.3	3.7	1.6	1.7	3.6	27.5	2
CAG-17	9.4	2.4	1.5	1.5	3.5	26.9	2
CAG-18	12.1	2.6	2.4	2.7	5	35.8	2.2
CAG-19	6.7	2.5	2.1	1.8	4.7	33.9	2.1
CAG-20	6.8	2.3	1.7	1.7	3.7	28.2	2.1
CAG-21	6.1	2.7	1.9	1.9	3.9	30.5	2.2
CAG-22	12.9	2.5	2.7	1.3	5.3	38.2	2.3
CAG-23	5.8	2.4	2	1.8	4.2	31.4	2.2
CAG-24	6.9	3.3	2.3	1.6	4.5	34.6	2.2
CAG-25	5.9	2.4	1.8	1.8	3.8	28.8	2.1

Mean	9.69	2.76	2.18	1.72	4.45	33.58	2.15
CD (P = 0.05)	0.51	0.14	0.11	0.09	0.23	1.78	0.11
SE(m)	0.18	0.05	0.04	0.03	0.08	0.62	0.04
SE(d)	0.26	0.07	0.06	0.05	0.12	0.88	0.06
CV (%)	3.24	3.24	3.24	3.18	3.18	3.22	3.28

Fig. 1. Experimental field showing twenty-five *Capsicum annuum* L. genotypes cultivated under a coconut ecosystem at the Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore

 **A**	 **B**

C

D

E

F

Fig. 2. Representative variation in plant growth and architecture among selected *Capsicum annuum* L. genotypes cultivated under a coconut ecosystem. Panels A–F represent contrasting plant growth habits and canopy architecture observed under field conditions.

A)

B)

Fig. 3. Variation in fruit morphology among selected *Capsicum annuum* L. genotypes cultivated under a coconut ecosystem (A) Variation in fruit length (B) Variation in fruit diameter