International Journal of Research in Agronomy 2025; 8(1): 107-114

E-ISSN: 2618-0618
P-ISSN: 2618-060X
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www.agronomyjournals.com
2025; 8(1): 107-114
Received: 08-11-2024
Accepted: 14-12-2024

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Exploring reproductive traits of indigenous coconut (*Cocos nucifera* L.) accessions: Implications for crop improvement

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DOI: https://doi.org/10.33545/2618060X.2025.v8.i1b.2352

Abstract
Coconut (*Cocos nucifera* L.) is an economically significant crop in tropical and subtropical regions, and understanding the variability in its reproductive traits is essential for enhancing breeding programs aimed at improving productivity and adaptation. This study characterized 31 indigenous coconut accessions conserved in National Coconut Gene Bank of ICAR-CPCRI Research Centre, Kidu that hosts ICG, SA&ME in Karnataka, India, to assess key reproductive traits. The study revealed significant diversity in several traits, including inflorescence length, which ranged from 96.33 cm in Horned Coconut Tall to 148.50 cm in Kodiaghat Brown Tall. Similarly, the number of male flowers per inflorescence varied from 4,460 in Ponnani Yellow Tall to 9,085 in Indian West Coast Tall, while pollen output ranged from 3.30 g in Ponnani Yellow Tall to 14.02 g in Dugong Creek Tall. Number of female flowers per inflorescence ranged from 12.92 in Kutiadi Tall to 57.87 in Champin Micro Tall. Correlation analysis identified several significant associations among the reproductive traits in the studied population. Inflorescence length was positively correlated with the length of spikelet bearing portion (r = 0.841**) and the length of stalk (r = 0.821**), suggesting that larger inflorescences are associated with longer spikelet-bearing portions and stalks. Notably, number of female flowers per inflorescence was negatively correlated with length of spikelet (r = -0.444*). Moreover, a significant positive correlation was observed between male flower production and pollen output (r = 0.694**), indicating that genotypes with higher male flower production tend to produce more pollen. These findings underscore considerable variability in reproductive traits across the evaluated accessions, highlighting the potential for selecting superior coconut genotypes that exhibit larger inflorescences, enhanced pollen production, and optimal flower production. Such traits are valuable for improving breeding strategies focused on increasing coconut yield, quality, and adaptability to varying environmental conditions.

Keywords: Coconut, reproductive traits, accessions, inflorescence length, male flowers, female flowers, pollen output, breeding

Introduction

Coconut (*Cocos nucifera* L.) is one of the most versatile and critical crop that holds immense socio-economic importance in tropical and subtropical regions around the world (Nampoothiri *et al.*, 2018) [14]. Coconut referred to as "Tree of Life," plays a crucial role in the livelihoods of millions of people, particularly in developing countries (Mohan Kumar and Kunhamu, 2022) [13]. It is used for a wide range of purposes, from food and beverage products to medicinal uses, cosmetics, and construction materials (Mat *et al.*, 2022) [11]. The coconut palm thrives in a variety of environments, from coastal areas to inland plains, and its fruit, especially the coconut water and copra, serves as a primary source of food, income, and raw materials for millions of people, particularly in coastal areas (Devi and Ghatani, 2022) [5]. Globally, coconut is cultivated across 12.25 million hectares in more than 90 countries, but, Philippines, Indonesia, and India accounts for 75 per cent of the total growing area. In India, coconut is grown in 2.27 million hectares, with Kerala, Karnataka, Tamil Nadu, and Andhra Pradesh collectively contributing to 90 per cent of the cultivated area. Coconut cultivation not only supports the livelihoods of millions of farmers but also provides rural employment, forming the backbone of rural economies in coastal regions. In the 2022-23 period, coconut contributed approximately Rs. 30,795 crores to India's GDP and earned export revenue of around Rs. 7,577 crores (CDB, 2023). The global demand for coconut products, particularly for oil, has seen significant growth in recent decades, further underscoring the importance of this crop in global agricultural markets (Rethinam, 2019; Grass Ramirez *et al*., 2023) [21, 7].

The genus *Cocos*, that includes coconut (*Cocos nucifera* L.), is a monotypic taxon within the subfamily *Arecoideae*, a group that also includes other economically important palm genera such as *Phoenix* (date palm), *Elaeis* (oil palm), *Borassus* (palmyrah), and *Caryota* (fish tail palm) (Dransfield and Uhl, 1986; Uhl and Dransfield, 1987) [6, 28]. All coconut varieties are diploid, with a chromosome count of 2n = 2x = 32. Coconut palms are unbranched and aerial, with the crown enclosing a single shoot apical meristem (SAM), resulting in indeterminate flowering (Tomlinson, 1990) [27]. The leaves are arranged in an alternate phyllotaxy, spiralling in either a left-handed or right-handed direction (Davis, 1972) [4]. The interval between the initiation of successive leaves and inflorescences is influenced by factors such as genotype, soil fertility, and seasonal conditions. Under typical conditions, a coconut palm produces an average of 12–15 leaves annually, with an inflorescence emerging from the axil of each leaf (Menon and Pandalai, 1958) [12].

Coconut stands out as one of the few major horticultural crops that lacks closely related wild relatives, highlighting the critical importance of conserving its genetic diversity. However, the genetic diversity of coconut populations is increasingly threatened by both biotic and abiotic stresses, underscoring the need for conservation efforts (Batugal *et al*., 2005) [2]. In this context, ICAR-CPCRI at its Research Centre, Kidu, hosts a vast collection of indigenous and exotic coconut germplasm conserved in its national gene bank, in addition to the accessions maintained in its international coconut gene bank for South Asia & the Middle East. This valuable germplasm repository serves as a key resource for coconut breeding and research, providing access to diverse genetic material that supports the development of improved coconut varieties. The climate at ICAR-Central Plantation Crops Research Institute (CPCRI) Research Centre, Kidu, Karnataka, is characterized by a tropical monsoon climate with distinct wet and dry seasons. Coconut palms thrive in warm, humid tropical climates, with an ideal temperature range of 26 °C to 27 °C and a diurnal variation of 7-8 °C for optimal growth and development (Marar and Pandalai, 1958; Child, 1964) [10, 3]. The effects of temperature and rainfall on coconut palms have been studied in various regions (Thampan, 1981; Vanaja and Amma, 2002; Timothy, 2010) [25, 29, 26]. For the development of improved coconut varieties, it is essential to thoroughly characterize the conserved coconut populations in order to identify accessions with superior traits that can be integrated into breeding programs. Reproductive success plays a pivotal role in assessing the adaptability and productivity potential of these conserved accessions. By evaluating key traits such as floral biology, flowering synchronization, and fruit set across various accessions, researchers can pinpoint varieties with higher reproductive performance. This is crucial for selecting the most promising parental materials, ultimately aiding the development of high-yielding and resilient coconut varieties.

Materials and Methods

Fig 1: Location of ICAR-CPCRI RC, Kidu, Karnataka

The study was conducted at the ICAR-Central Plantation Crops Research Institute, Research Centre, Kidu, Karnataka, India located in the geographic coordinates of latitude of 12.30° N and longitude of 75.20°E with an altitude of 291.0 meters above mean sea level (MSL) (Figure 1). The region experiences an average maximum temperature of 40 °C during the summer and 33 °C in winter. The average minimum temperature ranges from 24 °C in summer to 18 °C in winter. The annual rainfall at the centre varies between 2800 mm and 4200 mm, contributing to a humid tropical climate conducive to coconut cultivation.

31 indigenous coconut accessions (including check variety Indian West Coast Tall) collected from Kerala, Lakshadweep Islands, and Andaman & Nicobar Islands (Table 1) and conserved in the National Coconut Gene Bank of this Research Centre (which also hosts International Coconut Gene Bank for South Asia & Middle East) were used for studying the reproductive traits. The data on reproductive characters were collected over two consecutive years, during 2020-21 to 2021-22. The experimental was set up in Randomized Block Design (RBD) with three replications, and two palms per replication were used for recording observations. Inflorescences produced on each palm were tagged, and floral traits such as length of inflorescence, length of the spikelet-bearing portion, length of inflorescence stalk, length of spikelet, number of spikelets

inflorescence-1, and numbers of male and female flowers inflorescence-1 were recorded. Additional parameters such as the number of inflorescences palm-1, duration of male and female phases, intra-spadix overlapping of male and female phases, pollen output and fruit setting % were also measured according to coconut descriptors (Ratnambal *et al*., 1995, 2000) [18, 19]. The collected data were analysed statistically using SPSS and R software.

Table 1: List of coconut accessions selected for reproductive traits study

Sl. No.	Accession Name	Source of the Germplasm
1	Pinarai Tall	Kerala
2	Mullasseri Tall	Kerala
3	Pavaratty Tall	Kerala
4	Pallissery Tall	Kerala
5	Chappadan Tall	Kerala
6	Ponnani Tall	Kerala
7	Ponnani Tall Yellow	Kerala
8	Kakkadipuram Tall	Kerala
9	Chengara Tall	Kerala
10	Manjeri Tall	Kerala
11	Koothali Tall	Kerala
12	Kutiadi Tall	Kerala
13	Quilandi Tall	Kerala
14	Mahi Tall	Kerala
15	Achamthruthy Tall - I	Kerala
16	Laccadive Ordinary Tall Agathi	Lakshadweep Islands
17	Laccadive Micro Tall Agathi	Lakshadweep Islands
18	Laccadive Micro Tall Agathi Oval fruited	Lakshadweep Islands
19	Laccadive Small Tall Agathi	Lakshadweep Islands
20	Champin Micro Tall	Andaman & Nicobar Islands
21	Nicobar Micro Tall Katchal	Andaman & Nicobar Islands
22	Nicobar Micro Tall	Andaman & Nicobar Islands
23	Kodiaghat Brown Tall	Andaman & Nicobar Islands
24	Andaman Horned Tall	Andaman & Nicobar Islands
25	Carbin Brown Tall	Andaman & Nicobar Islands
26	Dugong Creek Tall	Andaman & Nicobar Islands
27	Malaca Tall	Andaman & Nicobar Islands
28	Nicobar Tall Katchal	Andaman & Nicobar Islands
29	Nicobar Tall AuckChung	Andaman & Nicobar Islands
30	Nicobar Tall Tamaloo	Andaman & Nicobar Islands
31	Indian West Coast Tall	Kerala (check)

Results and Discussion

Length of inflorescence: The length of inflorescence varied from 96.33 cm (Andaman Horned Tall) to 148.50 cm (Kodiaghat Brown Tall) with a population mean of 123.20 cm. Among the thirty one accessions, sixteen accessions including check variety recorded length of inflorescence greater than the population mean. In accessions collected from Kerala, Achamthruthy Tall – I (133.83 cm) followed by Quilandi Tall (131.89 cm) recorded higher inflorescence length. Among the accessions from Lakshadweep Islands, Laccadive Micro Tall Agathi Oval Fruited (128.58 cm) and Laccadive Ordinary Tall Agathi (122.25 cm) recorded higher inflorescence length as compared to Laccadive Small Tall Agathi that recorded lowest length of inflorescence (Fig. 2). Similarly in accessions from Andaman and Nicobar Islands, Kodiaghat Brown Tall, Dugong Creek Tall and Nicobar Tall Katchal had higher inflorescence length. These results align with Niral *et al*. (2008) [15], who found that tall accessions generally have larger inflorescences compared to dwarf varieties.

Length of spikelet bearing portion: The length of spikelet bearing portion ranged from 28.50 cm to 50.83 cm with overall population mean value of 40.05 cm (Fig. 2). Kodiaghat Brown Tall recorded the highest length of spikelet bearing portion followed by Champin Micro Tall (46.08 cm), Indian West Coast Tall (45.63 cm) and Mullasseri Tall (45.19 cm), while, the lowest length of spikelet bearing portion was observed in Andaman Horned Tall. Similar variations have been reported in coconut germplasm by Singh *et al*. (2020) [23].

Length of inflorescence stalk: The highest length of inflorescence stalk (73.33 cm) was recorded in Kodiaghat Brown Tall, followed by Achamthruthy Tall - I (69.00 cm) and Ponnani Tall (66.83 cm). Whereas, shortest stalk length was observed in Laccadive Small Tall Agathi (46.13 cm), followed by Nicobar Tall Tamaloo (52.42 cm) and Andaman Horned Tall (52.83 cm). The length of inflorescence stalk in Kerala, Lakshadweep Island and Andaman and Nicobar Islands ranged between 55.67 cm to 69 cm, 46.13 cm to 64.08 cm and 52.42 cm to 73.33 cm, respectively (Fig. 2). Diversity in floral traits of coconut has been extensively documented by several researchers (Patil *et al*., 1993; Kumaran *et al*., 2004; Niral *et al*., 2008; Singh *et al*., 2020) [16, 8, 15, 23], with notable differences observed particularly in stalk length.

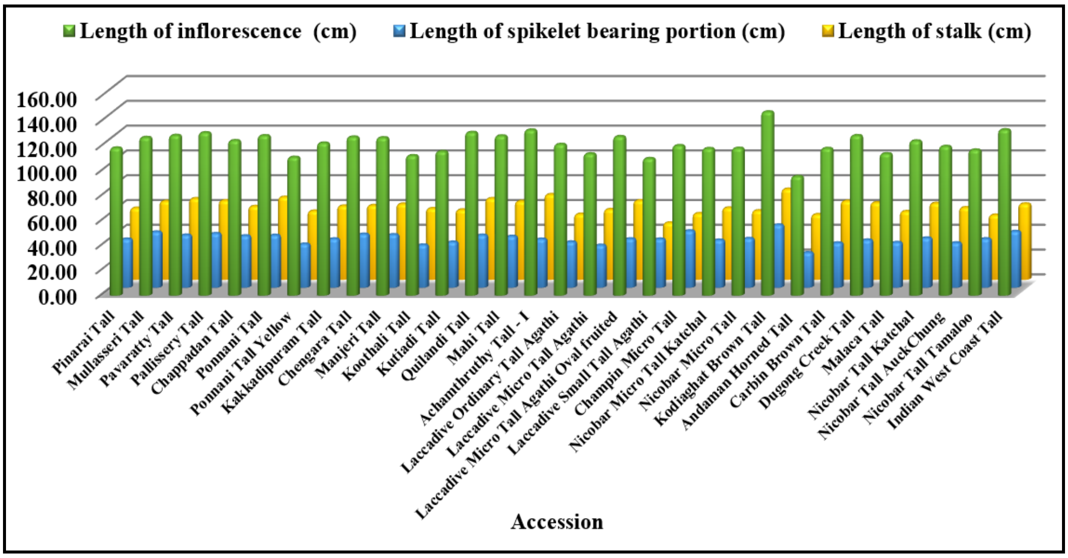

Fig 2: Length of inflorescence, length of spikelet bearing portion and length of stalk among the coconut accessions

Length of spikelet: The check variety, Indian West coast Tall had the longest length of spikelet (41.69 cm), closely followed by Kodiaghat Brown Tall (40.58 cm), Mullasseri Tall (39.07 cm) and Kutiadi Tall (38.52 cm), while the lowest length of spikelet was observed in Andaman Horned Tall (23 cm). The length of spikelet in accessions native to Kerala, Lakshadweep Island and Andaman and Nicobar Islands ranged between 31.46 cm to 39.07 cm, 34.50 cm to 36.89 cm and 23 cm to 40.58 cm, respectively. Overall the population studied had an average spikelet length of 35.73 cm (Table 2). Spikelet length in the conserved coconut germplasm at ICAR-CPCRI Kasaragod has been reported to range from 27 to 55 cm (Ratnambal *et al*., 1995, 2000; Niral *et al*., 2008) [18, 19]. This variation highlights the diversity in length of spikelet among the studied coconut accessions.

Number of spikelets inflorescence^{-1}: The number of spikelets inflorescence^{-1} varied significantly among the coconut accessions. The highest number (33.0) was recorded in Chengara Tall, while the lowest (24.67) was observed in Laccadive Micro Tall Agathi Oval Fruited. Other accessions with higher spikelet counts included Andaman Horned Tall (32.0), Manjeri Tall (31.33), and Dugong Creek Tall (31.0). On the other hand, Laccadive Micro Tall Agathi Oval Fruited (24.67), Ponnani Tall Yellow (27.0), and Laccadive Small Tall Agathi (27.33) exhibited the lowest numbers of spikelets inflorescence^{-1}. The overall population in the study had an average of 29.23 spikelets inflorescence^{-1} (Table 2). The findings are consistent with those reported by Balakrishnan *et al*. (1988) [1], who observed a similar variation in the number of spikelets inflorescence^{-1}, ranging from 20 to 65, across different coconut varieties. This reinforces the notion of considerable variability in spikelet numbers among coconut accessions.

Number of male flowers inflorescence^{-1}: The variation in the number of male flowers per inflorescence observed in this study aligns with findings from previous research on coconut floral traits. The number of male flowers per inflorescence ranged from 3457.30 to 9085.13, with an overall population mean of 6282.89 (Table 2). The highest number of male flowers was recorded in the check variety, Indian West Coast Tall (9085.13), followed closely by Dugong Creek Tall (8869.43), Carbin Brown Tall (8192.27), and Andaman Horned Tall (7250.12). These numbers suggest that certain tall varieties, particularly the Indian West Coast Tall, possess a notably higher number of male flowers per inflorescence, which could contribute to their higher reproductive capacity. On the other hand, accessions with the lowest numbers of male flowers included Laccadive Micro Tall Agathi Oval Fruited (3457.30), Ponnani Tall Yellow (4460.45), and Kutiadi Tall (4966.65). The variation in the number of male flowers is also evident when comparing accessions from different geographic regions. Accessions from Kerala exhibited a range of 4460.45 to 6796.73 male flowers, those from Lakshadweep Islands ranged from 3457.30 to 6747.37, and those from Andaman and Nicobar Islands ranged from 4987.15 to 9085.13. These findings are consistent with previous studies on coconut floral traits, such as those by Ratnambal *et al*. (1995, 2000) [18, 19] and Niral *et al*. (2008) [15], which also observed considerable variation in the number of male flowers per inflorescence. Such variation is influenced by genetic factors, as well as environmental conditions, and may have important implications for coconut breeding programs. Increased male flower production is often correlated with higher pollination rates, which can directly impact yield and fruit set, making this trait an important consideration for improving coconut productivity.

Number of female flowers inflorescence^{-1}: The mean number of female flowers per inflorescence in the studied coconut accessions ranged from 12.92 to 57.87, with a population mean of 23.17 (Table 2). The highest number of female flowers was recorded in Champin Micro Tall (57.87), which was on par with Andaman Horned Tall (52.64). Other accessions with relatively high numbers of female flowers included Nicobar Micro Tall Katchal (33.74) and Laccadive Micro Tall Agathi (33.58). On the other hand, the lowest number of female flowers per inflorescence was observed in Kutiadi Tall (12.92), Malaca Tall (14.83), and Nicobar Tall Katchal (14.83), indicating considerable variation across the accessions. These findings suggest that while certain accessions, such as Champin Micro Tall and Andaman Horned Tall, have a high number of female flowers per inflorescence, others exhibit lower numbers, which could have implications on fruit setting, fruit size and overall yield. Female flowers are critical for fruit production, and accessions with a higher number of female flowers could potentially offer advantage in terms of higher yield. This variation in female flower production is consistent with similar studies on coconut floral traits, such as those by Niral *et al*. (2008) [15] and Patil *et al*. (1993) [16], which also documented significant variation in the number of female flowers among different coconut accessions.

Colour of the spikelet: The colour of the spikelet was measured using RHS colour chart. Among the accessions studied, fifteen different colour variants have been observed for colour of the spikelet trait (Table 3). Among the thirty one accessions studied, eight accessions had their spikelet colour as light yellow (17D), three accessions with strong orange yellow (163B) and three accessions with deep orange yellow (163A).

Colour of the female flower: The colour of the female flower was measured using RHS colour chart, among the accessions studied, 14 different colour variants have been observed for colour of the female flower trait (Table 3). Among the accessions studied, seven accessions had light yellow (17D) coloured female flower, similarly three accessions had strong orange yellow (163B), three accessions with light yellow green (2C) and three accessions with deep orange yellow (163A).

Duration of male and female phase: No significant difference was observed in the duration of the male and female phases among the accessions studied. However, Andaman Horned Tall had the longest male phase, lasting 21.28 days, followed by Kakkadipuram Tall (20.06 days), Indian West Coast Tall (19.83 days), and Quilandi Tall (19.78 days). Regarding the female phase, the shortest duration was recorded in Kutiadi Tall (2.83 days), while the longest was observed in Andaman Horned Tall (4.50 days). Other accessions with longer female phase durations included Nicobar Micro Tall (4.22 days), Pinarai Tall (4.11 days), and Pallissery Tall (3.67 days).

Intra-spadix overlapping of male and female phase: Intra-spadix overlapping of the male and female phases was absent in all thirty-one accessions studied. This suggests that the male and female phases occurred sequentially rather than concurrently within the same spadix, indicating a clear separation between the reproductive phases in the coconut varieties examined. Similar results in tall coconut types have been reported by (Regi and Josephrajkumar, 2013) [20]

Table 2: Inflorescence characters of the coconut accessions

Germplasm	LoS (cm)	$NoSI^{-1}$	$NoMFI^{-1}$	$NoFFI^{-1}$	DtFP	DoMP	DoFP
Pinarai Tall	37.94	29.72	6046.59	18.10	17.94	16.50	4.11
Mullasseri Tall	39.07	28.28	6274.30	22.26	20.83	19.00	3.11
Pavaratty Tall	33.25	28.17	6306.83	18.09	19.67	18.17	3.33
Pallissery Tall	36.03	28.00	5420.67	16.85	19.17	17.67	3.67
Chappadan Tall	37.75	30.17	6705.45	20.96	19.83	17.72	3.11
Ponnani Tall	35.12	28.89	5487.51	18.19	21.11	19.44	3.50
Ponnani Tall Yellow	31.46	27.00	4460.45	20.68	18.33	17.25	3.00
Kakkadipuram Tall	34.80	28.89	5989.46	19.94	21.56	20.06	3.17
Chengara Tall	35.25	33.00	6265.98	27.66	19.33	17.67	3.33
Manjeri Tall	34.96	31.33	5878.47	17.96	20.83	19.50	3.33
Koothali Tall	33.22	29.33	6039.62	17.52	19.00	17.17	3.50
Kutiadi Tall	38.52	27.67	4966.65	12.92	20.67	17.83	2.83
Quilandi Tall	37.03	29.11	5160.73	19.17	22.67	19.78	3.44
Mahi Tall	38.50	28.67	6725.33	20.54	20.50	18.50	3.50
Achamthruthy Tall - I	38.33	29.78	6796.73	25.81	21.56	19.39	3.50
Laccadive Ordinary Tall Agathi	36.89	29.44	5287.98	18.33	19.56	18.00	3.33
Laccadive Micro Tall Agathi	34.50	27.67	5085.74	33.58	20.00	18.00	3.17
Laccadive Micro Tall Agathi Oval fruited	36.42	24.67	3457.30	19.51	20.67	18.33	3.00
Laccadive Small Tall Agathi	35.25	27.33	6747.37	26.08	19.72	17.06	3.33
Champin Micro Tall	35.04	30.72	5807.81	57.87	18.17	16.44	3.33
Nicobar Micro Tall Katchal	34.08	30.56	7209.30	33.74	20.72	18.83	3.28
Nicobar Micro Tall	36.46	30.33	6443.06	24.54	21.39	18.72	4.22
Kodiaghat Brown Tall	40.58	28.50	4987.15	21.74	20.22	18.67	3.00
Andaman Horned Tall	23.00	32.00	7250.12	52.64	24.00	21.28	4.50
Carbin Brown Tall	34.18	29.33	8192.27	16.50	20.33	18.83	3.33
Dugong Creek Tall	35.75	31.00	8869.43	18.08	21.00	19.33	3.33
Malaca Tall	35.42	29.72	8337.04	14.83	19.83	18.00	3.39
Nicobar Tall Katchal	35.49	29.06	6413.00	15.83	20.39	18.61	2.89
Nicobar Tall AuckChung	36.74	29.00	6589.60	15.87	20.33	17.50	2.92
Nicobar Tall Tamaloo	34.92	28.83	6482.50	25.28	19.67	17.83	3.50
Indian West Coast Tall	41.69	29.83	9085.13	27.17	21.83	19.83	3.33
Mean	35.73	29.23	6282.89	23.17	20.35	18.42	3.36
S. Ed	2.88	1.45	1126.70	3.59	1.38	1.29	0.42
CD at 5 %	5.77	2.90	2253.39	7.17	2.77	NS	NS
CV (%)	9.89	6.09	21.96	18.96	8.33	8.56	15.29

LoS - Length of spikelet, $NoSI^{-1}$ - Number of spikelets $inflorescence^{-1}$, $NoMFI^{-1}$ - Number of male flowers $inflorescence^{-1}$, $NoFFI^{-1}$ - Number of female flowers $inflorescence^{-1}$, DtFP - Days to female phase, DoMP - Duration of male phase, DoFP - Duration of female phase.

Inter-spadix overlapping of male and female phase: Inter-spadix overlapping, where the male and female phases overlap between different spadices on the same palm, exhibited considerable variability across coconut accessions. Some varieties, including Pinarai Tall, Mullasseri Tall, Pavaratty Tall, Ponnani Tall, Chengara Tall, Kutiadi Tall, Mahi Tall, Champin Micro Tall, Andaman Horned Tall, Carbin Brown Tall, Dugong Creek Tall, Nicobar Tall AuckChung, Nicobar Tall Tamaloo, and Indian West Coast Tall, demonstrated this overlap, suggesting that male and female flowers are available simultaneously across different spadices, which could extend the pollination window and enhance fertilization chances. In contrast, other accessions did not show inter-spadix overlapping. This variation suggests that accessions with overlapping of male and female phases between the spadices of same palm, may have increased opportunities for successful fertilization. Inter-spadix overlapping of male and female phases among tall coconut cultivars has been reported by various workers (Samanta, 2009; Thomas and Josephrajkumar, 2013) [22, 20].

Fresh weight and dry weight of male flowers $inflorescence^{-1}$: The highest fresh weight of male flowers $inflorescence^{-1}$ was observed in Dugong Creek Tall (842.17 g), Malaca Tall (823.22 g), and Carbin Brown Tall (774.28 g), while the lowest values were recorded in Laccadive Micro Tall Agathi Oval Fruited (294.12 g), Ponnani Tall Yellow (382.00 g), and Laccadive Ordinary Tall Agathi (388.43 g). The overall mean for fresh weight was 594.25 g. Regarding the dry weight of male flowers $inflorescence^{-1}$, Malaca Tall (334.69 g), Dugong Creek Tall (309.08 g), and Carbin Brown Tall (327.23 g) again showed the highest values. In contrast, the lowest dry weight values were observed in Laccadive Micro Tall Agathi Oval Fruited (120.93 g), Ponnani Tall Yellow (149.48 g), and Laccadive Ordinary Tall Agathi (147.53 g). The overall mean values for fresh and dry weight were 594.25 g and 236.32 g, respectively, with coefficients of variation (CV) of 21.58% and 19.85% (Table 4). These values suggest substantial variability in both fresh and dry male flower production, which could be important for selecting accessions with higher reproductive potential for breeding programs. Similar results have been reported by Niral *et al.* (2008) [15] among different coconut varieties.

Table 3: Variability in colour of the spikelet and colour of the female flower across the coconut accessions

Germplasm	Colour of the spikelet	Colour of the female flower
Pinarai Tall	Strong Orange Yellow (163B)	Strong Orange Yellow (163B)
Mullasseri Tall	Strong Greenish Yellow (153B)	Strong Greenish Yellow (153B)
Pavaratty Tall	Brilliant Yellow Green (150C)	Brilliant Yellow (9C)
Pallissery Tall	Strong Greenish Yellow (153C)	Strong Greenish Yellow (151B)
Chappadan Tall	Brilliant Yellow Green (150C)	Brilliant Yellow (9C)
Ponnani Tall	Strong Orange Yellow (17A)	Strong Orange Yellow (17A)
Ponnani Tall Yellow	Light Greenish Yellow (1C)	Brilliant Greenish Yellow (3B)
Kakkadipuram Tall	Light Greenish Yellow (8B)	Light Greenish Yellow (8C)
Chengara Tall	Strong Orange Yellow (163B)	Strong Orange Yellow (163B)
Manjeri Tall	Vivid Yellow (16A)	Light Yellow (17D)
Koothali Tall	Brilliant Yellow (21C)	Light Greenish Yellow (5C)
Kutiadi Tall	Light Yellow (17D)	Light Yellow (17D)
Quilandi Tall	Vivid Yellow (16A)	Light Yellow (17D)
Mahi Tall	Light Yellow (17D)	Light Yellow (17D)
Achamthruthy Tall - I	Brilliant Yellow (10A)	Brilliant Yellow (10A)
Laccadive Ordinary Tall Agathi	Pale Orange Yellow (16D)	Pale Orange Yellow (16D)
Laccadive Micro Tall Agathi	Light Yellow (17D)	Light Yellow (17D)
Laccadive Micro Tall Agathi Oval fruited	Light Yellow (17D)	Light Yellow Green (2C)
Laccadive Small Tall Agathi	Strong Orange Yellow (17A)	Strong Orange Yellow (17A)
Champin Micro Tall	Strong Orange Yellow (163B)	Strong Orange Yellow (163B)
Nicobar Micro Tall Katchal	Light Yellow (17D)	Light Yellow Green (2C)
Nicobar Micro Tall	Light Yellow (17D)	Light Yellow (17D)
Kodiaghat Brown Tall	Deep Orange Yellow (163A)	Deep Orange Yellow (163A)
Andaman Horned Tall	Strong Yellow Green (N144A)	Strong Yellow Green (N144A)
Carbin Brown Tall	Deep Orange Yellow (163A)	Deep Orange Yellow (163A)
Dugong Creek Tall	Light Yellow (17D)	Light Yellow (17D)
Malaca Tall	Light Yellow (17D)	Light Yellow Green (2C)
Nicobar Tall Katchal	Brilliant Yellow (21C)	Light Greenish Yellow (5C)
Nicobar Tall AuckChung	Deep Orange Yellow (163A)	Deep Orange Yellow (163A)
Nicobar Tall Tamaloo	Pale Orange Yellow (16D)	Pale Orange Yellow (16D)
Indian West Coast Tall	Strong Greenish Yellow (151B)	Strong Greenish Yellow (151B)

Pollen output inflorescence^{-1}: The highest pollen outputs were observed in Dugong Creek Tall (14.02 g), Mahi Tall (13.73 g), Nicobar Tall AuckChung (12.69 g), Carbin Brown Tall (12.39 g), and Nicobar Micro Tall (12.09 g). These accessions, with their larger pollen output, are likely to have a greater potential for pollination, potentially contributing to higher fertilization rates if other factors are favourable. On the other hand, the lowest pollen output values were recorded in Ponnani Tall Yellow (3.30 g), Laccadive Micro Tall Agathi Oval Fruited (4.23 g), Andaman Horned Tall (4.67 g), and Laccadive Ordinary Tall Agathi (4.85 g). The overall mean pollen output inflorescence^{-1} across all accessions was 8.67 g, suggesting that, on average, most coconut accessions produce moderate levels of pollen. However, the high coefficient of variation (CV) of 41.15% (Table 4) indicates significant variability in pollen production, highlighting that some accessions produce considerably more pollen than others. This variation could be due to genetic differences among the accessions, as well as environmental factors that may influence pollen production. These findings are in good conformity with the observation of Manthriratna (1965) [9], who reported that, pollen yield per inflorescence varies from a little over 1 g in some dwarf coconut varieties to about 10 g in tall varieties. Similar results have been reported by Srinivasu *et al.* (2022) [24] among different coconut varieties in coastal Andhra Pradesh.

Number of inflorescences palm^{-1}: Significant difference was observed for number of inflorescences palm^{-1} across the coconut accessions (Table 4). The highest number of inflorescences per palm was observed in the check variety, Indian West Coast Tall (17.0), followed closely by Nicobar Micro Tall (16.83), Quilandi Tall (16.25), and Mahi Tall (15.67). These accessions, with a higher number of inflorescences, may have greater potential for producing more flowers and, consequently, higher fruit yields, assuming other factors like pollination and flower fertility are optimal. On the other hand, the lowest number of inflorescences palm^{-1} was recorded in Carbin Brown Tall (9.33), followed by Kutiadi Tall (11.42), Nicobar Tall Katchal (11.42), Laccadive Micro Tall Agathi (12.0), Dugong Creek Tall (12.50), and Malaca Tall (12.50). Ratnambal *et al.* (1995, 2000) [18, 19] and Niral *et al.* (2008) [15], also observed variations for number of inflorescences palm^{-1}.

Correlation between the reproductive traits in the studied population: The correlation analysis of reproductive traits in the studied population revealed a mix of strong, moderate, and weak relationships among the variables, with some significant positive and negative correlations (Table 5). Strong positive correlation was observed between length of inflorescence (LoI) and length of spikelet-bearing portion (LoSBP) (r = 0.841, p<0.01), suggesting that as the length of the inflorescence increases, so does the length of the spikelet-bearing portion. Similarly, length of inflorescence and length of stalk (LoSt) were also positively correlated (r = 0.821, p<0.01), as were LoSBP and LoSt (r = 0.527, p<0.01). These results suggest that these three traits viz. inflorescence length, spikelet-bearing portion length, and stalk length are likely to co-vary, potentially due to shared growth patterns or genetic factors influencing inflorescence structure. The length of spikelet (LoSp) showed positive correlations with both LoSBP (r = 0.677, p<0.01) and LoI (r = 0.729, p<0.01), suggesting that longer inflorescences and spikelet-bearing portions are associated with larger spikelets. Similar positive correlation among the above traits have been reported by Singh *et al*. (2020) [23] in coconut germplasm. However, LoSp was negatively correlated with number of female flowers inflorescence^{-1} (NoFFI^{-1}) (r = -0.444, p<0.05). In line with previous studies, Niral *et al*. (2008) [15] reported that the number of female flowers in an inflorescence exhibited a negative correlation with length of spikelet. The negative correlation between these traits aligns with our findings, indicating that, while there may be a trade-off between these reproductive structures. Number of spikelets inflorescence^{-1} (NoSI^{-1}) showed positive correlations with number of male flowers inflorescence^{-1}. Number of male flowers inflorescence^{-1} (NoMFI^{-1}) was positively correlated with fresh weight of male flowers (FWMFI^{-1}) (r = 0.902, p<0.01) and dry weight of male flowers (DWMFI^{-1}) (r = 0.794, p<0.01), and pollen output inflorescence^{-1} (POI^{-1}) (r = 0.694, p<0.01) suggesting accessions with more number of male flowers inflorescence^{-1} are associated with a higher pollen output inflorescence^{-1}.

Table 4: Fresh and dry weight of male flowers inflorescence^{-1} and pollen output inflorescence^{-1} of the coconut accessions

Germplasm	FWoMFI^{-1} (g)	DWoMFPI^{-1} (g)	POI^{-1} (g)	NoIP^{-1}
Pinarai Tall	561.97	222.15	8.51	13.92
Mullasseri Tall	604.45	261.92	8.82	15.00
Pavaratty Tall	618.42	226.50	7.08	13.42
Pallissery Tall	517.92	221.93	6.59	12.75
Chappadan Tall	669.98	298.02	7.46	13.50
Ponnani Tall	533.23	205.68	9.73	14.25
Ponnani Tall Yellow	382.00	149.48	3.30	14.00
Kakkadipuram Tall	558.95	214.73	8.49	13.75
Chengara Tall	582.92	229.53	8.96	15.17
Manjeri Tall	632.17	251.50	10.11	15.00
Koothali Tall	560.33	215.41	6.86	12.75
Kutiadi Tall	524.00	213.18	6.09	11.42
Quilandi Tall	530.72	224.24	7.61	16.25
Mahi Tall	644.08	240.85	13.73	15.67
Achamthruthy Tall - I	594.75	211.50	8.08	14.08
Laccadive Ordinary Tall Agathi	388.43	147.53	4.85	14.33
Laccadive Micro Tall Agathi	578.09	205.06	6.58	12.00
Laccadive Micro Tall Agathi Oval fruited	294.12	120.93	4.23	12.83
Laccadive Small Tall Agathi	632.72	271.27	7.65	13.08
Champin Micro Tall	604.42	241.22	9.65	14.42
Nicobar Micro Tall Katchal	646.38	252.18	11.04	14.17
Nicobar Micro Tall	643.73	276.36	12.09	16.83
Kodiaghat Brown Tall	484.08	212.15	5.51	14.00
Andaman Horned Tall	617.67	248.12	4.67	12.67
Carbin Brown Tall	774.28	327.23	12.39	9.33
Dugong Creek Tall	842.17	309.08	14.02	12.50
Malaca Tall	823.22	334.69	10.60	12.50
Nicobar Tall Katchal	639.77	276.94	9.02	11.42
Nicobar Tall AuckChung	681.48	269.79	12.69	12.58
Nicobar Tall Tamaloo	523.17	187.15	10.76	12.83
Indian West Coast Tall	732.25	259.73	11.50	17.00
Mean	594.25	236.32	8.67	13.66
S. Ed	104.70	38.30	2.91	0.92
CD at 5 %	209.39	76.59	5.82	1.85
CV (%)	21.58	19.85	41.15	8.29

FWoMFI^{-1}-Fresh weight of male flowers inflorescence^{-1}, DWoMFI^{-1} -Dry weight of male flowers inflorescence^{-1}, POI^{-1} -Pollen output per inflorescence^{-1}, NoIP^{-1}-Number of inflorescences palm^{-1}

Table 5: Correlation among the reproductive traits in the studied population

	LoI	LoSBP	LoSt	LoSp	NoSI^{-1}	NoMFI^{-1}	NoFFI^{-1}	DtFP	FWMFI^{-1}	DWMFI^{-1}	POI^{-1}
LoI	--										
LoSBP	.841**	--									
LoSt	.821**	.527**	--								
LoSp	.729**	.677**	.404*	--							
NoSI^{-1}	-0.084	-0.009	-0.099	-0.222	--						
NoMFI^{-1}	-0.1	-0.101	-0.104	-0.012	.550**	--					
NoFFI^{-1}	-0.34	-0.078	-0.345	-.444*	.374*	0.082	--				
DtFP	0.014	-0.163	0.225	-0.174	0.19	0.25	0.138	--			
FWMFI^{-1}	-0.076	-0.049	-0.043	0.019	.531**	.902**	0.029	0.193	--		
DWMFI^{-1}	-0.084	0.009	-0.048	0.027	.479**	.794**	-0.016	0.168	.940**	--	
POI^{-1}	0.149	0.153	0.056	0.269	.406*	.694**	-0.085	0.111	.757**	.660**	--

LoI - Length of inflorescence, LoSBP - Length of spikelet bearing portion, LoSt – Length of stalk, LoSp - Length of spikelet, NoSI^{-1} - Number of spikelets inflorescence^{-1}, NoMFI^{-1} - Number of male flowers inflorescence^{-1}, NoFFI^{-1} - Number of female flowers inflorescence^{-1}, DtFP - Days to female phase, FWMF^{-1} – Fresh weight of male flowers inflorescence^{-1}

Conclusion
This study highlights significant variability in reproductive traits across 31 coconut accessions from diverse regions. Accessions like Kodiaghat Brown Tall, Dugong Creek Tall, and Achamthruthy Tall - I demonstrated higher reproductive potential, with certain varieties, such as Champin Micro Tall and Andaman Horned Tall, showing superior female flower counts. Variation in male and female phases, floral productivity, and pollen output was observed, with few accessions showing higher fertilization potential. These findings provide valuable insights for selecting promising parental materials in coconut breeding programs aimed at improving productivity.

Acknowledgement
The authors would like to express their sincere gratitude to ICAR-Central Plantation Crops Research Institute (CPCRI), Kasaragod, Kerala, for invaluable support throughout the course of this study. We also extend our heartfelt thanks to the project assistants under the RFS scheme for their dedicated assistance in climbing coconut palms to record observations, which greatly contributed to the success of this research.

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