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Germplasm evaluation in *Cinnamomum tamala*: A potential climate-resilient crop

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Indian Bay Leaf (*Cinnamomum tamala*) is an important tree spice that has been valued as a food flavorant, natural colourant, preservative, and raw material for the pharmaceutical industry. Considering its increasing demand, its cultivation has been expanding in the tropical and subtropical regions of the world. As a leaf is the material of commerce, there is relatively less dependence of the crop on environmental factors for the induction of flowering and subsequent events of fruiting. This makes the crop more relevant in a changing climate. Horticultural evaluation to identify superior genotypes has not been attempted in this species so far, and the selection criteria are lacking. In the present study, variability in morphological, yield, and biochemical parameters (essential oil content, oleoresin content, chlorophyll and carotenoid content, essential oil GC-MS profiling) was assessed in six accessions of tejpat from 2021 to 2025, revealing significant differences. Considering superior fresh leaf yield (1974.3 leaves/ m; 1819.5 g/m), dry yield (960.5 g/m), dry recovery (52.79%), higher chlorophyll content (3.578 µg/g), high essential oil content (0.463%), and high eugenol content, the accession IC653497 was found to be promising. This is the first study on perennial evaluation of germplasm in Indian Bay Leaf. The study generates information on important quality parameters to be considered for the selection of elite types in this species that would be helpful for future crop improvement programmes in this climate-resilient species.

Keywords: Chlorophyll, Essential oil, Eugenol, Germplasm, Indian bay leaf

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Introduction

Cinnamomum tamala (Buch.-Ham.) T.Nees & C.H.Eberm. (Indian Bay Leaf/ Tejpat/ Indian Cassia) is an evergreen, hardy species of the Lauraceae family that can thrive in temperate as well as tropical climates[1]. The species is native to Assam, Bangladesh, South and Central China, Eastern and Western Himalayas, Laos, Myanmar, Nepal, and Vietnam[2]. In India, it has been reported to be naturally distributed in the 450-2500 m altitudinal ranges of the Himalayas in Arunachal Pradesh, Uttarakhand, Himachal Pradesh, Assam, Meghalaya, Mizoram, Sikkim, West Bengal, apart from cultivation in the Andaman Islands of India[1,3-5]. The monoecious tree is evergreen, 6-20 m tall, and has lanceolate, glabrous leaves[6].

The species has traditionally been used as a spice for culinary preparations, in medicinal formulations, as a fodder, and timber[5]. Studies have suggested the species to be rich in pharmaceutically important bioactive molecules, and several biological activities have been reported in it. The major activities include antidiabetic, antioxidant, anti-ulcer, antimicrobial, cytotoxic, anti-inflammatory, acaricidal, anti-hyperlipidemic, analgesic, antipyretic, anti-diarrhoeal, anti-aflatoxigenic, lipid-lowering, gastro-protective, *etc*.[5,7]. The species has been an integral part of ayurvedic formulations like *Chyawanprash*, *Sudarshan choorna*, *Aswagandharishtam, Trijata, Talisadi churna*, *Khadirarishta*, *Chandraprabha vati etc*.[8-10], apart from being an ingredient of choice in the herbal teas[1].

Most of the produce is generally collected from the wild[1]; however, considering the increasing demand for the species, systematic cultivation has been initiated in some parts of India and Nepal[10]. The species being cross-pollinated and commonly seed propagated[11], natural variability is present in the wild, as revealed from the variation for the bioactive molecules obtained from different regions[12]. Further, Gwari *et al.*[3] have reported genetic variability among eight collections from the Uttarakhand Himalayas based on molecular characterisation. However, so far, systematic studies on its horticultural evaluation are lacking.

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The recent scenario of a changing climate demands diversification of crop husbandry with crops that have better capabilities to cope with the environmental extremes. The crop has more climate resilience potential than many other horticultural crops as (a) leaf is the economic part which makes it less prone to climatic extremes than those in which flowers/ fruits are the economic produce, (b) limited incidence of pests/ diseases noticed in the crop[1], unlike many other crops in which changing climate could wreak havoc due to sudden surge of pests/ pathogens, and (c) perennial nature provides opportunity for year-round harvests.

Thus, the present study was conducted to understand the variations among the collections of Indian Bay Leaf for morphological, yield, and quality parameters for the identification of superior germplasm. The traits highlighted here could be used as selection criteria in the crop improvement of Indian Bay leaf.

Materials and Methods

Experimental site

The experiment was conducted between 2021 and 2025 at the Division of Horticulture and Crop Improvement, ICAR-Central Island Agricultural Research Institute, Sri Vijaya Puram, Andaman and Nicobar Islands, India. Weather parameters of the experimental site during the study period have been presented in Table 1. Six well-grown trees located in the premises of the Institute's Garacharma Farm were selected to determine the variability among them for various traits. The passport information of these collections was submitted to the ICAR-National Bureau of Plant Genetic Resources, New Delhi, India, and indigenous collection numbers were obtained for those.

Leaf morphology and yield contributing traits

Leaf morphological parameters were recorded using recently matured leaves. Leaf length, leaf width, and petiole length were recorded using a measuring scale and expressed in cm. The weight of fresh leaf was recorded using an analytical balance (CY-120, Citizen, India) and expressed in g. Twenty leaves were used for recording morphological parameters. For the estimation of yield attributing parameters, branches with one meter of brown wood were harvested and brought to the laboratory. The number of leaves on each harvested stem was counted and expressed as the number of leaves per meter of branch. Fresh leaf yield (g/m) and dry leaf yield (g/m)

Table 1 — Weather parameters of the experimental site during the period of experimentation

Month	Rainfall (Total) (mm)					No. of Rainy days					Mean relative humidity (%)					Mean (max/min) temperature (°C)				
	2021	2022	2023	2024	2025	2021	2022	2023	2024	2025	2021	2022	2023	2024	2025	2021	2022	2023	2024	2025
Jan	25.5	67.8	3.5	150.0	37.6	2	2	1	4	3	68	71	67	71	70	30.2/ 24.7	30.6/ 25.0	30.5/ 23.4	30.7/ 24.6	30.2/ 24.4
Feb	92.2	105.3	29.4	2.6	28.2	4	6	2	1	2	71	73	68	73	72	30.5/ 24.1	30.1/ 23.5	30.9/ 23.9	30.9/ 24.2	30.8/ 23.7
Mar	0.0	76.5	11.9	0.0	0.0	0	4	2	0	0	72	73	69	67	68	32.2/ 25.0	31.5/ 25.2	31.6/ 25.0	32.1/ 24.2	32.1/ 25.0
Apr	247.9	93.5	0.0	0.0	136.5	8	3	0	0	10	74	71	66	67	83	32.1/ 24.8	32.5/ 25.6	32.0/ 26.0	33.3/ 26.2	31.4/ 25.8
May	469.1	473.0	110.0	409.7	-	16	22	8	13	-	81	83	70	77	-	33.4/ 25.4	30.8/ 25.4	33.3/ 27.0	32.8/ 26.2	-
Jun	321.9	296.5	653.5	737.5	-	16	13	20	22	-	81	81	83	85	-	31.1/ 25.2	30.8/ 25.1	30.9/ 25.3	29.8/ 25.1	-
Jul	649.2	392.6	622.1	356.4	-	19	21	21	22	-	88	85	84	85	-	30.2/ 24.5	30.1/ 25.1	30.3/ 25.0	31.0/ 25.3	-
Aug	430.9	313.9	443.7	295.7	-	21	18	19	19	-	87	83	84	85	-	30.0/ 24.6	30.1/ 25.1	30.4/ 25.4	30.2/ 25.0	-
Sep	541.2	326.2	940.1	508.3	-	20	15	26	23	-	86	82	86	86	-	29.6/ 24.3	30.4/ 24.6	28.8/ 24.0	30.3/ 25.1	-
Oct	305.8	232.1	307.5	326.6	-	14	15	17	18	-	83	81	82	83	-	30.3/ 24.8	30.1/ 24.6	30.7/ 24.8	30.8/ 24.8	-
Nov	224.9	86.3	360.2	266.1	-	15	8	17	14	-	80	77	76	77	-	30.6/ 25.1	30.3/ 24.9	31.0/ 25.4	30.8/ 25.5	-
Dec	91.6	84.3	91.1	274.4	-	3	4	9	11	-	73	73	77	76	-	30.1/ 24.7	30.4/ 25.5	31.0/ 26.0	30.1/ 25.2	-

were determined using a digital tabletop scale. A known quantity (50 to 100 g) of fresh leaves was taken in a heavy-wall glass drying tray (Borosil, Mumbai, India) and dried in a hot air oven at 50°C. Drying was done with four replications, and dry recovery (%) was estimated.

Quality parameters

Photosynthetic pigments were determined in dried leaves using dimethyl sulphoxide (DMSO) as a solvent. For this, 0.125 g of leaf sample was accurately weighed using an analytical balance and incubated for 72 h in DMSO. The absorbance was measured using a UV-visible spectro-photometer (Biospectrometer, Eppendorf) at 665, 649, and 480 nm. Total chlorophyll content (µg/g) and total carotenoid content (µg/g) were calculated using the formulae given by Wellburn[13]. Royal Horticultural Society Colour Chart (RHS, 6th Edition, 2015–2019 Reprint) was used to characterise the leaf colour in fresh and dried leaves. Essential oil content (%) in the dried leaves was determined using Clevenger's apparatus, while oleoresin content (%) in the dried leaves was determined using acetone as a solvent in the Soxhlet apparatus. The analyses were done with two to four replications during each year. The essential oil profiling was carried out using gas chromatography- mass spectrometry (GC-MS/MS).

Essential oil profiling

The essential oil samples were diluted 1 to 10 times using dichloromethane, and 2 µL of it was injected into GC-MS/MS for the analysis. Essential oil profiling was carried out using Shimadzu Nexis GC-2030 coupled with Shimadzu TQ 8040 NX ion trap mass selective detector. A fused silica capillary column (SH-I-5Sil MS; Column ID: 1655684) of 30 mm × 0.25 mm id, and 0.25 µm film thickness was used for the purpose. Initial oven temperature was set to 60°C for 5 min and was increased by 3°C/min upto 210°C, after which it was held for 1 min. The temperature was further increased to 250°C at the rate of 8°C/ min and held for 4 min with a total run time of 65 min. Injector and detector temperatures were maintained at 260°C, ion source-heating at 230°C, while interface temperature was at 240°C. EI-mode at 70 eV with full scanrange (40-400 amu) was used. Helium at a flow rate of 1 mL/min was employed, and injection was initially in split-less mode followed by split mode (1:30) after 5 min. The compounds were identified by comparing the retention index using two spectral libraries available as Flavour and Fragrance Natural and Synthetic Compounds and National Institute of Standards and Technology, 2020.

Statistical analysis

Data collected for various parameters during different years of analysis and pooled data were subjected to analysis of variance (ANOVA), and mean separation was done using the least significant difference. For this, the Web Agri Stat Package (WASP 2.0, ICAR-CCARI, Goa, India) was used. Data on essential oil content were presented as mean ± standard error of mean.

Results

During the present study, six individual trees of Indian bay leaf were identified and systematically studied under the warm and humid climatic conditions of the Andaman Islands from 2021 to 2025. The results of the study suggested wide variations for some parameters, while others remained unaffected among the collections.

Leaf parameters

Leaves are the prime economic part of the Indian Bay Leaf, although the bark is also used as a substitute for true cinnamon. Leaf morphological parameters were recorded for three years, i.e., 2021, 2023, and 2024. The year-wise and pooled data have been presented in Table 2. During the first and third year of evaluation, the differences for leaf length among the accessions were significant, while they remained statistically similar during the second year of study. Leaf length ranged between 12.96 cm (IC653498) and 17.18 cm (IC653500), between 13.75 cm (IC653497) and 15.54 cm (IC653496); while it varied between 14.53 cm (IC653499) and 15.94 cm (IC653500) during the three study years. Pooled data analysis for three years suggested that the accession IC653500 had the highest values for leaf length. In the case of leaf width, the differences among the accessions were significant. Leaf width ranged from 3.52 to 4.83 cm, 4.10 to 4.73 cm, and 4.17 to 4.57 cm during 2021, 2023, and 2024, respectively. Pooled data analysis showed that the accession IC653500 had the widest leaves (4.71 cm), which was on par with IC653497 (4.40 cm). Petiole length showed significant variations only during the first year of evaluation, while it remained statistically similar in all the collections during 2023, 2024, and the pooled analysis. Individual leaf weight showed significant differences during all the years of evaluation and in pooled data analysis. Heaviest leaves were observed in collections IC653500 during 2021 and 2024, while

Table 2 — Leaf parameters in six collections of Indian Bay Leaf under Andaman conditions during evaluation

Collection	Leaf Length (cm)				Leaf Width (cm)				Petiole Length (cm)				Leaf weight (g)			
	2021	2023	2024	Pooled	2021	2023	2024	Pooled	2021	2023	2024	Pooled	2021	2023	2024	Pooled
IC653496	15.09 d	15.54 a	15.67 ab	15.43 b	4.05 b	4.65 ab	4.49 ab	4.39 b	1.24 bc	1.22 a	1.28 a	1.25 a	0.864 c	1.196 a	1.039 a	1.033 b
IC653497	16.14 bc	13.75 a	15.45 ab	15.11 bc	4.14 b	4.40 bc	4.30 bc	4.40 a	1.35 ab	1.26 a	1.14 a	1.25 a	0.986bc	0.974 b	0.904bc	0.954 c
IC653498	12.96 e	13.77 a	15.15 bc	14.76 c	3.52 c	4.59 ab	4.37 a-c	4.16 c	1.22 c	1.11 a	1.41 a	1.24 a	0.662 d	1.137 a	0.946 b	0.915 c
IC653499	16.81 ab	14.17 a	14.53 c	15.02 bc	4.69 a	4.10 c	4.17 c	4.32 bc	1.37 ab	1.13 a	1.11 a	1.20 a	1.038 b	0.973 b	0.835 c	0.949 c
IC653500	17.18 a	15.17 a	15.94 a	16.25 a	4.83 a	4.73 a	4.57 a	4.71 a	1.48 a	1.18 a	1.18 a	1.28 a	1.239 a	0.976 b	1.121 a	1.112 a
IC653501	15.37 cd	15.09 a	15.34 ab	15.18 bc	4.05 b	4.45 ab	4.42 ab	4.30 bc	1.46 a	1.04 a	1.29 a	1.20 a	0.952bc	0.991 b	0.928 b	0.957 b

Values followed by different alphabet in a column indicate significant differences using the least significant difference at 5% level of significance

accession IC653496 showed the highest values during 2023 and 2024, although IC653498 remained on par with it during 2023. Pooled data analysis showed significant superiority of accession IC653500 for leaf weight.

Yield parameters

Analysis of leaf yield parameters for 2024, 2025, and the pooled analysis has been presented in Table 3. Yield parameters were recorded in each meter of the harvested branch to maintain uniformity in comparison. The number of leaves per meter of harvested branch showed significant variation among the collections. Number of leaves per meter varied between 681.3 and 1427.7 during 2024, 941.8 and 2364.0 during 2025; while in the pooled data, it ranged between 844.2 and 1974.3. Throughout the study, the collection IC653496 showed the lowest number of leaves, while the collection IC653497 was consistently superior.

Leaf yield (fresh and dry) represents the interaction between individual leaf weight, number of leaves produced on the branch, and drying recovery (for dry yield alone). During 2024, fresh leaf yield remained statistically similar, while significant variations were noticed in the other two data series. In the case of dry leaf yield, variations were significant during both years as well as the pooled analysis. The accession IC653497 showed consistency in yield, and significantly, the highest values for fresh (1290.2, 2137.1, and 1819.5 g/m) as well as dry leaf (681.1, 1128.1, and 960.5 g/m) yields were recorded in it; however, marginally low but statistically similar yields were observed in the accession IC653498. For dry recovery, pooled data analysis suggested the significantly highest value of 52.79% in IC653497 (Fig. 1), while it remained statistically similar with IC653498 (52.77%). Dry recovery ranged between 45.53 and 52.79% among the collections.

Quality parameters

Retention of colour after drying of the leaves was assessed by determining the photosynthetic pigments. During both the years of analysis and in the pooled data, the total chlorophyll content was consistently significantly highest in the collection IC653497 (Table 4). As high as 3.578 µg/g total chlorophyll was recorded in the pooled data of this collection, which remained statistically similar to IC653500 (3.281 µg/g). A similar trend was noticed in the case of total carotenoid content as well, wherein IC653497 showed the consistently highest values in both the years of analysis (0.578 µg/g and 0.366 µg/g) and in pooled analysis (0.472 µg/g), while IC653500 remained on par during the second year and pooled analysis. RHS colour chart values for fresh leaf samples as well as leaf powder samples have been presented in Table 5.

Table 3 — Yield Parameters of six collections of Indian Bay Leaf over two years

Characters	Year	IC653496	IC653497	IC653498	IC653499	IC653500	IC653501
Leaf yield (nos./m)	2024	681.3 c	1324.7 ab	836.3 bc	710.0 c	1427.7 a	840.7 bc
	2025	941.8 d	2364.0 a	1984.6 b	1232.8 d	972.8 d	1643.8 c
	Pooled	844.2 d	1974.3 a	1554.0 ab	1036.8 cd	1143.4 b-d	1342.6 bc
Fresh leaf yield (g/m)	2024	814.9 a	1290.2 a	950.9 a	690.9 a	1393.4 a	833.1 a
	2025	978.5 c	2137.1 a	1877.4 ab	1029.4 c	1090.5 c	1604.5 b
	Pooled	917.2 cd	1819.5 a	1530.0 ab	902.4 d	1204.1 b-d	1315.2 bc
Dry leaf yield (g/m)	2024	384.4 b	681.1 a	501.8 ab	322.9 b	681.5 a	379.3 b
	2025	461.6 c	1128.1 a	990.7 a	481.1 c	533.4 c	730.6 b
	Pooled	432.6 b	960.5 a	807.4 a	421.8 b	588.9 b	598.8 b

Values followed by different alphabet in a row indicate significant differences using the least significant difference at 5% level of significance

Table 4 — Total Chlorophyll content and total carotenoids in the dried leaves of six collections of Indian Bay Leaf

Collection	Total chlorophyll content (µg/g)			Total carotenoids content (µg/g)		
	2021	2022	Pooled	2021	2022	Pooled
IC653496	2.090e	2.155c	2.123b	0.324e	0.290b	0.307b
IC653497	4.150a	3.005a	3.578a	0.578a	0.366a	0.472a
IC653498	2.392d	2.751ab	2.571b	0.352cd	0.348a	0.350b
IC653499	3.070c	1.597d	2.333b	0.339d	0.243c	0.291b
IC653500	3.986b	2.576b	3.281a	0.558b	0.355a	0.457a
IC653501	2.933c	1.876cd	2.405b	0.363c	0.259c	0.311b

Values followed by different alphabet in a column indicate significant differences using the least significant difference at 5% level of significance

Essential oils and oleoresins are important quality parameters in spices, which were determined in the present study. The essential oil content varied from 0.20 to 0.40%, 0.40 to 0.45%, 0.27 to 0.60%, and 0.375 to 0.463% during 2022, 2023, 2025, and the pooled analysis, respectively (Table 6). The highest essential oil content was observed in the collection IC653497. Oleoresin content varied from 7.96 to 14.16%, 8.08 to 12.15%, and 9.25 to 12.32% during 2021, 2022, and in the pooled analysis, respectively (Fig. 2). However, except for the first year, the results remained statistically similar among the collections.

Overall, 67 compounds were identified in the studied collections using GC-MS/MS, of which 32 compounds were common in all the collections, while 5 compounds were detected in 5 out of 6 collections (Table 7). Individual collections contained 45 (IC653497) to 48 (IC653498) compounds. Eugenol was, invariably, the most dominant compound in all the collections; however, its content varied between 38.52% (IC653500) and 44.96% (IC653497). There were several compounds, which were present in quantities higher than 1% in at least one of the accessions. These included α-Pinene (0.00 to 1.21%), α-Phellandrene (2.84 to 5.21%), o-Cymene (2.96 to 4.86%), Eucalyptol (2.36 to 3.01%), 3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-, (R)- (1.03 to 1.26%), α-Terpineol (2.31 to 2.81%), Bicyclo[7.2.0]undec-4-ene, 4,11,11-trimethyl-8-methylene-,[1R-(1R*,4Z,9S*)]- (4.86 to 5.46%), Copaene (3.28 to 3.80%), Aromandendrene (1.57 to 1.90%), 1,4,7,-Cycloundecatriene, 1,5,9,9-tetramethyl-, Z,Z,Z- (0.00 to 1.50%), (1R,2S,6S,7S,8S)-8-Isopropyl-1-methyl-3-methylene tricyclo[4.4.0.02,7]decane-rel- (0.63 to 1.82%), Naphthalene, decahydro-4a-methyl-1-methylene-7-(1-methylethenyl)-, [4aR-(4a.α.,7.α.,8a.β.)]- (1.63 to 2.07%), Naphthalene, 1,2,3,4,4a,5,6,8a-octahydro-7-methyl-4-methylene-1-(1-methylethyl)-, (1.α.,4a.β.,8a.α.)- (0.19 to 1.24%), Naphthalene, 1,2,4a,5,8,8a-

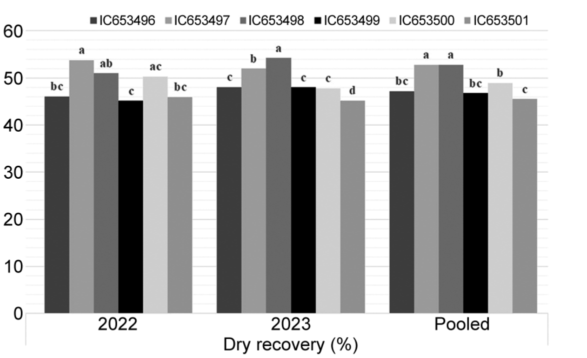

Fig. 1 — Dry recovery (%) in six collections of Indian Bay Leaf over two years (Values followed by different alphabet in a year indicate significant differences using least significant difference at 5% level of significance).

Table 5 — RHS colour chart values for fresh and dried samples

Collection	Side	Fresh leaf sample	Powdered sample
IC653496	Front	Fan 3, Green group, 143 A- Strong Yellow Green	Fan 3, Yellow-Green group, 144 B- Strong Yellow Green
	Back	Fan 3, Green group, 138 B- Moderate Yellow Green	
IC653497	Front	Fan 3, Green group, 141 B- Deep Yellowish Green	Fan 3, Yellow-Green group, 143C- Strong Yellow Green
	Back	Fan 3, Green group, 138 B- Moderate Yellow Green	
IC653498	Front	Fan 3, Green group, 141 A- Deep Yellowish Green	Fan 3, Yellow-Green group, 144 B- Strong Yellow Green
	Back	Fan 3, Green group, 138 B- Moderate Yellow Green	
IC653499	Front	Fan 3, Green group, 141 B- Deep Yellowish Green	Fan 3, Yellow-Green group, 144 B- Strong Yellow Green
	Back	Fan 3, Green group, 138 B- Moderate Yellow Green	
IC653500	Front	Fan 3, Green group, 138 A- Moderate Yellowish Green	Fan 3, Green group, 143 B- Strong Yellow Green
	Back	Fan 3, Green group, 138 B- Moderate Yellow Green	
IC653501	Front	Fan 3, Green group, 143 C- Strong Yellow Green	Fan 3, Yellow-Green group, 144 B- Strong Yellow Green
	Back	Fan 3, Yellow-Green group, 145 B- Light Yellow Green	

Table 6 — Essential oil content (%) in leaves of six collections of Indian Bay Leaf

Collection	2022	2023	2025	Pooled
IC653496	0.35±0.05	0.45±0.05	0.40±0.00	0.413
IC653497	0.40±0.00	0.43±0.03	0.60±0.00	0.463
IC653498	0.40±0.00	0.43±0.03	0.27±0.01	0.380
IC653499	0.20±0.00	0.45±0.03	0.50±0.10	0.400
IC653500	0.40±0.00	0.40±0.00	0.50±0.10	0.425
IC653501	0.30±0.00	0.40±0.00	0.40±0.00	0.375

Values are mean ± SEM

hexahydro-4,7-dimethyl-1-(1-methylethyl)-, [1S-(1.α.,4a.β.,8a. α.)]- (1.07 to 1.49%), 1H-Cycloprop[e]azulene, 1a,2,3,5,6,7,7a,7b-octahydro-1,1,4,7-tetramethyl-, [1aR-(1a. α.,7. α.,7a.β.,7b. α.)]- (1.89 to 2.53%), 1H-Cycloprop[e]azulen-7-ol, decahydro-1,1,7-trimethyl-4-methylene-, [1ar-(1a. α.,4a. α.,7. α.,7a.β.,7b. α.)]- (3.61 to 5.81%), 1H-Cycloprop[e]azulen-4-ol, decahydro-1,1,4,7-tetramethyl-, [1aR-(1a. α.,4.β.,4a.β.,7. α.,7a.β.,7b. α.)]- (0.86 to 1.18%), (1S,2E,6E,10R)-3,7,11,11-Tetramethylbicyclo[8.1.0]undeca-2,6-diene (2.62 to 4.58%), Germacrene B (1.00 to 2.53%), (-)-Globulol (1.14 to 1.70%), (-)-Spathulenol (1.29 to 1.84%), α-Humulene (0.00 to 1.02%) and (1R)-2,6,6-Trimethylbicyclo[3.1.1]hept-2-ene (0.00 to 1.03%).

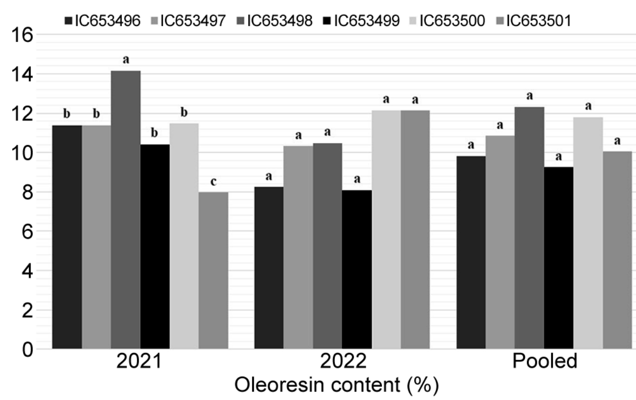

Fig. 2 — Oleoresin content (%) in leaves of six collections of Indian Bay Leaf (Values followed by different alphabet in a year indicate significant differences using least significant difference at 5% level of significance

Discussion

The genus *Cinnamomum* is known to have a number of species with potential for utilisation.

However, systematic crop improvement efforts have not been made in most of these species, except for *C. verum*, wherein few improved varieties have been developed from India and Sri Lanka[14-15]. Considering the increasing demand for food, medicine, and other sectors, it is important to develop/ identify superior germplasm in this important tree spice, and the present work was a step in this direction. Further, the species being a potential climate-resilient crop, such studies would help in popularization of it in vulnerable regions.

Leaves are the economic part of the species, and leaf morphological parameters studied for three years suggested wide variations among the accessions. The evaluated plants being of seedling origin, variations among the collections for leaf morphology could be justified, as also reported in other tree species, *viz*. *C. burmanni* and *G. gummi-gutta*[16,17]. Leaf morphological variations have also been reported in improved varieties[14] and seedling population[18,19] of *C. verum*. Seasonal and diurnal

Table 7 — Leaf essential oil profiling in the studied collections of *Cinnamomum tamala*

Compounds	CAS no.	IC653496	IC653497	IC653498	IC653499	IC653500	IC653501
3-Hexen-1-ol, (E)-	928-97-2	0.30	0.37	0.29	0.18	-	0.26
Thujene <alpha->	2867-05-2	0.33	0.20	0.49	0.40	0.38	0.28
Pinene <alpha->	80-56-8	0.87	0.59	1.21	-	0.95	0.73
Pinene <beta->	127-91-3	0.63	0.45	0.86	0.80	0.80	0.61
Phellandrene <alpha->	99-83-2	3.61	2.84	4.38	5.21	5.10	4.50
3-Carene	13466-78-9	0.32	0.25	0.42	0.38	0.37	0.29
o-Cymene	527-84-4	3.96	4.15	4.86	3.80	3.48	2.96
Limonene	138-86-3	0.56	0.43	0.69	0.66	0.62	0.55
Eucalyptol	470-82-6	2.36	2.49	2.77	3.01	2.76	2.66
gamma.-Terpinene	99-85-4	0.28	-	0.32	0.39	0.39	0.32
(+)-4-Carene	29050-33-7	0.66	0.45	0.69	0.93	0.97	0.84
Cyclopropane, 2-(1,1-dimethyl-2-pentenyl)-1,1-dimethyl-	74663-76-6	0.40	0.72	0.30	-	-	-
3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-, (R)-	20126-76-5	1.06	1.26	1.15	1.16	1.03	1.15
.alpha.-Terpineol	98-55-5	2.31	2.81	2.43	2.61	2.41	2.72
Bicyclo[3.1.0]hexan-3-ol, 4-methylene-1-(1-methylethyl)-, (1.alpha.,3.alpha.,5.alpha.)-	3310-02-9	0.55	0.74	0.56	0.30	-	0.33
Bicyclo[7.2.0]undec-4-ene, 4,11,11-trimethyl-8-methylene-,[1R-(1R*,4Z,9S*)]-	118-65-0	4.90	4.86	5.13	5.13	5.35	5.46
Eugenol	97-53-0	41.23	44.96	39.02	42.50	38.52	40.62
Copaene	3856-25-5	3.31	3.53	3.77	3.80	3.28	3.37
Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, [1S-(1.alpha.,2.beta.,4.beta.)]-	515-13-9	0.34	0.36	0.36	0.35	0.43	0.51
gamma.-Muurolene	30021-74-0	0.75	0.64	0.74	-	-	-
alpha.-Maaliene	489-28-1	0.37	0.27	0.31	0.30	0.35	0.29
Aromandendrene	489-39-4	1.90	1.57	1.68	1.84	1.82	1.59
1,4,7,-Cycloundecatriene, 1,5,9,9-tetramethyl-, Z,Z,Z-	-	1.50	-	1.45	-	1.48	1.48
Alloaromadendrene	25246-27-9	0.46	0.35	0.38	0.43	0.45	0.37
Cadina-1(6),4-diene <10betaH->	20085-11-4	0.42	0.28	0.38	0.36	0.37	0.32
(1R,2S,6S,7S,8S)-8-Isopropyl-1-methyl-3-methylenetricyclo[4.4.0.02,7]decane-rel-	18252-44-3	1.14	0.63	1.15	1.14	1.55	1.82
Naphthalene, decahydro-4a-methyl-1-methylene-7-(1-methylethenyl)-, [4aR-(4a.alpha.,7.alpha.,8a.beta.)]-	17066-67-0	2.07	1.95	1.75	1.77	1.90	1.63
Naphthalene, 1,2,3,4,4a,5,6,8a-octahydro-7-methyl-4-methylene-1-(1-methylethyl)-, (1.alpha.,4a.beta.,8a.alpha.)-	39029-41-9	1.14	0.19	0.72	0.65	1.24	1.01
Naphthalene, 1,2,3,4,4a,7-hexahydro-1,6-dimethyl-4-(1-methylethyl)-	16728-99-7	0.29	-	0.26	0.21	-	
Naphthalene, 1,2,4a,5,8,8a-hexahydro-4,7-dimethyl-1-(1-methylethyl)-, [1S-(1.alpha.,4a.beta.,8a.alpha.)]-	523-47-7	1.49	1.07	1.43	1.13	1.40	1.34

(Contd.)

Table 7 — Leaf essential oil profiling in the studied collections of *Cinnamomum tamala (Contd.)*

Compounds	CAS no.	IC653496	IC653497	IC653498	IC653499	IC653500	IC653501
2-Naphthalenemethanol, 2,3,4,4a,5,6,7,8-octahydro-.alpha.,.alpha.,4a,8-tetramethyl-, [2R-(2.alpha.,4a.beta.,8.beta.)]-	63891-61-2	0.68	0.94	0.70	0.34	0.92	0.62
4a(2H)-Naphthalenol, 1,3,4,5,6,8a-hexahydro-4,7-dimethyl-1-(1-methylethyl)-, (1S,4R,4aS,8aR)-	19912-67-5	0.48	0.52	0.48	-	0.41	-
1H-Cyclopropa[a]naphthalene, 1a,2,3,3a,4,5,6,7b-octahydro-1,1,3a,7-tetramethyl-, [1aR-(1a.alpha.,3a.alpha.,7b.alpha.)]-	489-29-2	0.40	0.66	0.34	0.83	0.40	0.31
1H-Cycloprop[e]azulene, 1a,2,3,5,6,7,7a,7b-octahydro-1,1,4,7-tetramethyl-, [1aR-(1a.alpha.,7.alpha.,7a.beta.,7b.alpha.)]-	21747-46-6	2.40	1.89	2.16	2.53	2.46	2.17
1H-Cycloprop[e]azulen-7-ol, decahydro-1,1,7-trimethyl-4-methylene-, [1ar-(1a.alpha.,4a.alpha.,7.beta.,7a.beta.,7b.alpha.)]-	6750-60-3	5.08	5.81	5.36	3.63	3.86	3.61
1H-Cycloprop[e]azulen-4-ol, decahydro-1,1,4,7-tetramethyl-, [1aR-(1a.alpha.,4.beta.,4a.beta.,7.alpha.,7a.beta.,7b.alpha.)]-	552-02-3	1.08	1.01	0.96	0.86	1.25	1.18
(1S,2E,6E,10R)-3,7,11,11-Tetramethylbicyclo[8.1.0]undeca-2,6-diene	24703-35-3	3.24	2.62	2.83	3.41	4.12	4.58
(1S,4aR,7R)-1,4a-Dimethyl-7-(prop-1-en-2-yl)-1,2,3,4,4a,5,6,7-octahydronaphthalene	52026-55-8	-	-	-	0.19	-	-
(E)-2-((8R,8aS)-8,8a-Dimethyl-3,4,6,7,8,8a-hexahydronaphthalen-2(1H)-ylidene)propylformate	352457-47-7	0.31	-	-	-	-	-
cis-Calamenene	72937-55-4	0.41	-	0.40	-	0.39	-
(E)-1-Methyl-4-(6-methylhept-5-en-2-ylidene)cyclohex-1-ene	53585-13-0	0.51	0.25	0.39	0.35	0.29	0.33
Selina-3,7(11)-diene	6813-21-4	0.28	-	-	-	-	-
Germacrene B	15423-57-1	1.06	1.00	1.04	1.87	2.35	2.53
(-)-Globulol	489-41-8	1.70	1.23	1.18	1.14	1.37	1.37
tau.-Muurolol	19912-62-0	0.70	0.75	0.68	-	0.67	0.68
Phytol	150-86-7	-	-	-	-	-	0.36
Isospathulenol	88395-46-4	-	-	-	-	-	0.43
(-)-Spathulenol	77171-55-2	1.81	1.84	1.78	1.29	1.37	1.46
.alpha.-Bisabolol	515-69-5	-	-	0.25	-	-	-
Benzenemethanol, .alpha.,.alpha.,4-trimethyl-	1197-01-9	-	0.37	-	-	-	-
6-Isopropenyl-4,8a-dimethyl-1,2,3,5,6,7,8,8a-octahydro-naphthalen-2-ol	-	0.35	-	0.62	-	-	-
Caryophyllene oxide	1139-30-6	-	-	-	0.51	0.53	0.53

(Contd.)

Table 7 — Leaf essential oil profiling in the studied collections of *Cinnamomum tamala (Contd.)*

Compounds	CAS no.	IC653496	IC653497	IC653498	IC653499	IC653500	IC653501
(1aR,4S,4aR,7R,7aS,7bS)-1,1,4,7-Tetramethyldecahydro-1H-cyclopropa[e]azulen-4-ol	88728-58-9	-	-	-	-	0.27	0.58
(1aR,3aS,7S,7aS,7bR)-1,1,3a,7-Tetramethyldecahydro-1H-cyclopropa[a]naphthalen-7-ol	527-90-2	-	-	0.36	-	0.43	-
5-Azulenemethanol, 1,2,3,4,5,6,7,8-octahydro-.alpha.,.alpha.,3,8-tetramethyl-, acetate, [3S-(3.alpha.,5.alpha.,8.alpha.)]-	134-28-1	-	-	-	-	-	0.31
.alpha.-Cubebene	17699-14-8	-	-	-	0.17	-	0.27
Cubebene	29837-12-5	-	-	-	-	0.25	-
.gamma.-Elemene	29873-99-2	-	-	-	0.19	0.25	0.36
.alpha.-Muurolene	10208-80-7	-	0.26	0.26	0.30	-	-
Patchoulene<beta->	514-51-2	-	-	-	0.20	0.25	-
Humulene <alpha->	6753-98-6	-	0.97	-	1.02	-	-
Ocimene <(E)-, beta->	3779-61-1	-	-	-	0.39	0.47	0.33
Terpinene <alpha->	99-86-5	-	-	0.26	0.32	0.31	-
(1R)-2,6,6-Trimethylbicyclo[3.1.1]hept-2-ene	7785-70-8	-	-	-	1.03	-	-
.tau.-Cadinol	5937-11-1	-	0.28	-	-	-	-
Tau-Cadinol acetate	149197-48-8	-	0.38	-	-	-	-
[5-(Hydroxymethyl)-2,5,8a-trimethyl-1,4,4a,6,7,8-hexahydronaphthalen-1-yl]methanol diacetate	-	-	0.22	-	-	-	-
Total number of compounds		46	45	48	46	46	46
Total		100.00	99.41	100.00	100.00	100.00	100.00

variations have been reported to cause significant changes in the accumulation of primary and secondary metabolites in the leaves of *C. tamala*[20]. Similarly, Tansura *et al.*[21] have also reported the influence of season on the production of primary metabolites, secondary metabolites, pigments, and minerals. As these metabolites and constituents greatly contribute to the growth and development of plants, the variable results for leaf parameters in the studied accessions during different years of analysis could be justified. Even though these parameters vary with the environment, the chances of complete failure of the crop in this species are remote when compared to many other crops in which flowering and fruiting are decided by the climatic conditions prevailing in the region.

Yield parameters such as the number of leaves per meter of harvested branch, fresh leaf yield, dry recovery, and dry yield showed significant variations among the studied accessions. Earlier reports suggested that in the Nepal Himalayas, most of the tejpat is harvested from the wild plants of variable ages/ sizes[22]. The collectors try to harvest the maximum biomass from the tree, as the final produce is sold in the local markets on a quantitative basis and not on a quality basis[23]. In such cases, the actual harvested biomass per tree varies considerably and is generally non-uniform over the years. For example, fresh leaf yields increased between 18 kg in seedlings with 10-20 cm diameter at breast height (DBH) to 190 kg from seedlings of 50-60 cm DBH, when collected from the wild[22]. Parajuli[24] suggested dry leaf yields of 13 kg/tree/year; whereas a report by Lamichhane and Karna[22] suggested the yields of 8 to 20 kg/tree/year in the private plantations, depending on the local factors. In order to identify sustainable harvesting methods in tejpat, a study was conducted in the Nepal Himalayas[23], which suggested that the harvesting treatments, i.e., harvesting only lower $1/3^{rd}$, or lower $2/3^{rd,}$ or upper $1/3^{rd}$ branches, did not significantly impact the branch growth, leaf emergence, or biomass. They suggested that the lower $2/3^{rd}$ branches of the tree were suitable for harvesting with fresh leaf yields of 323.0 and 383.0 g and dry leaf yield of 132.0 and 187.0 g in two years of analysis[23]. Earlier reports suggested that new flushes occur at a higher frequency during monsoon months[20], and hence, the yields obtained in the present study were comparatively higher, probably due to higher rainfall, extended rainy season, and a greater number of rainy days in these islands (Table 1).

Dry recovery (%) is an important parameter that contributes to the overall yield in the spice crops, as these are sold in dried form[14,] and it has been reported to vary with the genotypes[16]. In the present study, dry recovery ranged between 45.53% and 52.79% among the collections. From the data of Choudhary *et al.*[23], it could be inferred that dry recovery of 40.86 to 48.83% was observed in *C. tamala* when the lower 2/3rd branches of the trees were harvested. Earlier study on improved varieties of *C. verum* suggested leaf dry recovery ranging between 46.5 and 66.7%[14].

The greenness in the leaves is mainly contributed by the chlorophylls, and retention of this greenness upon drying is an essential aspect in *C. tamala*[25]. It is known that after detachment from the plant during harvesting, the leaves get wounded and the ethylene is released[26]. Due to the chlorophyll degradation action of ethylene, the content of photosynthetic pigments decreases on harvesting and processing[25]. If a genotype exhibits better retention of pigments after drying, it is desirable as colour of the produce is one of the first sensory factors influencing the buyers' perception[27]. *C. tamala* has also been utilised traditionally for colouring in food and textiles[7], and hence, collection IC653497 with consistently higher contents of photosynthetic pigments holds promise. The results were also consistent with the RHS colour chart grading (Table 5).

Quality of the spices is mainly judged by the presence of essential oils and oleoresin contents in them[14] and hence, their determination is crucial in analysis of germplasm. Essential oil content is known to vary greatly in spices and aromatic plants as it is influenced by several factors, including genotypes, agro-climatic conditions, production, and postharvest operations, *etc*. Essential oil contents in *C. tamala* varied between 0.11 and 0.25% in response to the drying method employed, with the maximum being in oven-dried samples[28]. Hence, oven drying was adopted in the present study. It has been suggested that untimely harvesting (early or late harvesting) and high rainfall may deteriorate essential oil recovery[22]. High essential oils containing chemotypes of *C. tamala* with 1.2 to 3.9% (w/w) oil have been reported from northeastern India[12]. Hence, comparatively lower recovery of essential oils in the present study (0.375 to 0.463%) could be justified considering the heavy rainfall of the study region (Table 1). Intra-species and interspecific variability for essential oil content have also been reported in different species of *Cinnamomum*[29], which supports the findings of the present study. Essential oils and oleoresins of tejpat have been identified as natural food preservatives for pineapple-based beverage[30]. Hence, the superior germplasm identified during the present study could be useful for promoting such food processing industries in this region.

Literature review suggested that no reports on diversity/ crop improvement related studies are available in this species, except for a report on genetic diversity[3]. They suggested wide variability in eight collections of tejpat from the Uttarakhand Himalayas based on RAPD and ISSR markers. Even though the studies on the genetic/ phenotypic diversity are scarce in the species, several reports on chemical analysis of the species suggested the presence of chemotypes in the natural population. These chemotypes are named after the dominant constituents present in their essential oils, viz. eugenol type, cinnamaldehyde type, linalool type, trans sabinene hydrate-β-ocimene type *etc*.[5]. All the accessions in the present study had Eugenol as the dominant compound, and wide variability was observed for other compounds among the accessions studied. These results are in accordance with the earlier report[31], which suggested Eugenol as the dominant compound in the market samples of tejpat from Pondicherry.

It is a known fact that apart from the major compound (Eugenol in the present case), a number of other constituents are responsible for the aroma profile of any essential oil[20]. In the present study, there were 18 compounds with more than 1% content in IC653497 and their cumulative contribution was 86.89%, while 21 compounds each were more than 1% in IC653496, IC653501, and IC653500, with total percentages of 88.35, 89.21, and 88.10%, respectively. Twenty compounds, each contributing to more than 1% of the content, were detected in collections IC635498 and IC653499 with 86.53% and 89.02% cumulative content, respectively. Presence of minor compounds in the essential oil of spices has also been known to contribute to their biological activities, as reviewed by Sharma and Rao[5].

In the recent past, the popularity of the ayurvedic formulations has shown a significant rise, thereby demanding a regular supply of raw material[32]. The species has also been identified as a potential candidate for the development of eco-friendly natural herbicides[33]. Further, leaves have been identified as a feed additive in broiler production[34]. In order to promote such industries, large-scale raw material of uniform quality is a prerequisite to get products of uniform potency in each batch. Identification of superior germplasm, their vegetative propagation, and adoption of Good Agricultural Practices could help in significant scaling up of the production[3,32]. Efforts such as registration of Uttarakhand Tejpat as a Geographical Indication crop[35], distribution of quality planting material to the farmers, and facilitation of marketing have assisted in the promotion of cultivation of this crop in the state of Uttarakhand, India[36]. Similarly, production of vegetatively propagated planting material has given impetus for the cultivation of this valuable spice in the Andaman and Nicobar Islands[9]. Considering these points, the identified superior germplasm IC653497 could be of great practical utility in promoting this crop.

Conclusion

From the present study, it can be concluded that variability was present among tejpat accessions across various horticultural traits. Perennial evaluation of the accessions could help obtain repeatable and thus more reliable results. After evaluating the germplasm for plant morphology, yield, dry recovery, and biochemical parameters such as essential oil content, oleoresin content, colour retention, and essential oil profiling, accession IC653497 was found to be promising under Andaman Island conditions. As no guidelines for crop improvement are available for this important crop, this study could serve as a basis for selecting elite types in other parts of the country as well.

Conflict of interest

The authors of the present work declare that there are no conflicts of interest associated with this article.

AI use disclosure

No AI tool was used for manuscript preparation.

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