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RESEARCH ARTICLE

# Influences of seasons, tissue types and locations on endophytic fungi diversity associated with *Terminalia bellirica* (Gaertn.) Roxb.

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## Abstract

*Terminalia bellirica* is a traditional medicine plant used in various parts of the world. It has several properties, such as antimicrobial, and antioxidant, boosts immunity, regulates diabetes, and treats asthma, etc. Endophytic fungi reside within the plant tissue without causing plant disease symptoms. Endophytic fungi produce secondary metabolites that might play a pivotal role in conferring these pharmacological activities. Therefore, the present study was performed to unearth the novel endophytic fungi with seasonal influence from *T. bellirica*. A total of 643 endophytic fungal isolates were recovered from the leaves, barks, and roots of *T. bellirica* in three different seasons and identified at morphological levels. During the study, 26 culturable endophytic fungi including the non-sporulating forms belonging to 14 genera, 8 families, and 4 classes, were obtained. Ascomycota was found to be dominant (93%) and Mucoromycota (2%) was the least. The maximum isolate belongs to Sordariomycetes showing 47%. The isolation rate was found maximum in the root segments (0.62), while the colonization rate was recorded highest in the leaves (100%). However, the fungal endophytes were recovered maximum at Suryamaninagar (S1) site (180) followed by Debasthal (S5) site (147) and the least isolates were recovered at Ampinagar (S3) site (100). During the summer season, the highest total colonization frequency (CF) was detected by *Aspergillus niger* (124%) and *Colletotrichum gloeosporioides* in monsoon (156%) and winter seasons (92%). The maximum fungal isolates were obtained during the monsoon season (286) followed by the summer (202) and winter seasons (155). The colonization rate was higher during the monsoon season as compared to winter and summer, whereas the maximum isolation rate was recorded during the monsoon (0.76) than summer (0.54) and winter (0.41) seasons, respectively. The type of tissue, sampling locations, and seasons influences the endophytic fungal diversity and composition in this plant. Species diversity of endophytic fungi was found to be maximum during the monsoon season and minimum during the winter. The endophytic fungi recovered from this plant might be further explored for their biological activities, anticancer drugs, pharmaceutical and agricultural fertilizers, and may be used commercially.

Keywords: *Terminalia bellirica*; Medicinal Plant; Endophytic Fungi; Tissue Specificity; Diversity

## 1. Introduction

Fungi are one of the most diverse life forms in the planet Earth. The term “endophytes” was first used by Anton de Bary in 1866 for those fungi colonizing inside the living plant tissues. Fossil evidence of many plants indicated that plants have been associated with endophytic fungi for >400 million years (De Bary, 1866; Hardoim et al., 2015; Chetia et al., 2019). These fungi inhabit host plant tissues during a certain period of their life cycle and do not cause obvious disease symptoms to the host plant organs (Verma et al., 2021). They usually exist in various aquatic and terrestrial plants (Sarasan et al., 2017; Cosoveanu and Cabrera, 2018). The symbiotic relationship of fungal endophytes with the host plant benefitted against natural enemies such as pathogens and herbivores (Schardl et al., 2004; Singh et al., 2011); increased the resistance of plants to abiotic stress factors such as salinity and heavy metal toxicity in soil (Khan et al., 2014) and even promotes plant growth (Hamayun et al., 2010). Some of the endophytes are capable of producing bioactive compounds similar to the host plant. These bioactive compounds exhibited a wide range of applications in the fields of agriculture and medicine (Wu et al., 2013). Endophytic fungi are reported to produce a variety of secondary metabolites inside the plant tissues (Agusta, 2009). These metabolites from endophytic fungi showed important biological activities such as antibacterial, antioxidant, anticancer, immunomodulatory, antivirus, antituberculosis, anti-parasite, and insecticides (Hussain et al., 2014; Praptiwi et al., 2018).

Medicinal plants have become essential for treating several diseases originating from long-established practices of traditional medicine (Firenzuoli and Gori, 2007). The preparations of medicinal plants have eventually become an integral part of mainstream medicine after many ethnobotanicals and ethnopharmacological studies. Medicinal plants have formed a positive relationship with microbes in due course of evolution (Field et al., 2019; Yan et al., 2019). A reciprocal symbiotic relationship was found between endophytic fungi and host medicinal plants (Manganyi and Ateba, 2020). Endophytic fungi play a crucial role in enhancing resistance to abiotic stress in medicinal plants (Jia et al., 2016), improving secondary metabolism (Zhai et al., 2017), producing active ingredients (Ming et al., 2012), and promoting growth (Ye et al., 2020). Endophytic fungi have had a considerable impact on medicine, agriculture, and industry (Salehi and Safaie, 2024).

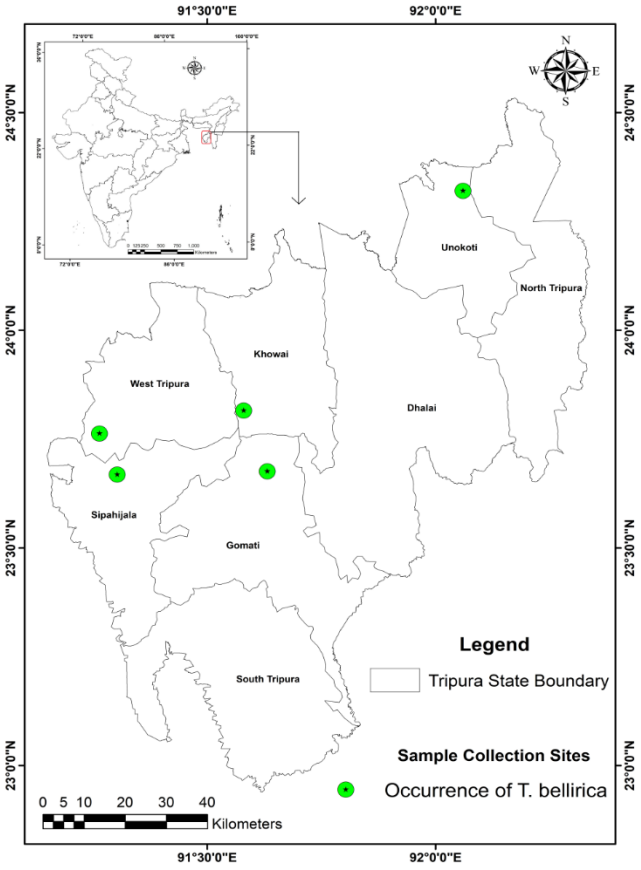


**Figure 1.** Map represents the collection sites of *T. bellirica* sample in different regions of Tripura.

associated with *T. bellirica*. Therefore, the present investigation was carried out to find out the influence of seasons, tissues, and locations on the colonization of culturable endophytic fungi within this plant. The present study also represented the species composition and distribution of culturable endophytic fungi inside the internal tissues of *T. bellirica*. This could pave the way for the discovery of new endophytic fungi that could have the potential to synthesize useful bioactive compounds.

## 2. Materials and methods

### *2.1. Study sites and sample collection*

Tripura is a small state located in the northeastern part of India and has a rich biodiversity. Healthy and mature plant samples were randomly collected from different collection sites viz. Suryamaninagar, Bishalgarh, Ampinagar, Hathai Kotor, and Debasthal during summer, monsoon, and winter seasons from January 2021 to December 2022 (Table 2; Figure 1). The distance of the collected plants was maintained at least 10-25 km away from each of the study sites. The plant samples were collected from different parts, namely the leaf, bark, and root of *T. bellirica* (Table 1). However, the root parts were collected from a depth of 10-20 cm beneath the ground using the iron toolbar. The samples were collected separately in pre-sterilized polythene bags and the collected samples were brought to the laboratory. It was then processed for the isolation of endophytic fungi within 24 hours of collection. A herbarium specimen (voucher No. TUH-2386) (Figure 2) of the plant sample was submitted to the Herbarium Centre in the Department of Botany, Tripura University for future reference.

### *2.2. Isolation and identification of endophytic fungi*

The collected plant samples were washed thoroughly in running tap water to remove the debris and dust from the surface of the tissues. A total of 1125 plant samples of different tissues were dissected separately. Subsequently, it was processed for surface sterilization as follows: Leaf, bark, and root samples were surface sterilized by dissolving into 70% ethanol (1 min), 2.5% sodium hypochlorite (30 sec) and 70% ethanol (30 sec) and were rinsed with sterilized distilled water nearly for 3 minutes (3 times), then allowed to surface dry under sterile conditions. The leaves were punched into circular segments (about 0.5 mm diameter) with the help of a sterile borer,

*Terminalia bellirica* (Gaertn.) Roxb. belongs to the family Combretaceae, found to grow in Nepal, Sri Lanka, Malaysia, and Southeast Asia (Ramesh et al., 2005). Vernacularly it is known as "Bahera" or Beleric or Myrobalan. The fruit of this medicinal plant is one of the major constituents of the ayurvedic remedy Triphala. *T. bellirica* is used to shield the liver, lower cholesterol levels in the body, and also used in the treatment of digestive as well as respiratory disorders (Latha and Daisy, 2011). This plant is a good antioxidant and lowers glucose levels due to the presence of polyphenolic compounds like gallic acid, tannins, flavones, etc. (Nampoothiri et al., 2011). The aqueous extract of *T. bellirica* fruits is used for the synthesis of zinc, iron, and copper oxide nanoparticles that are good biological and pharmaceutical agents to fight against different pathogens (Akhter et al., 2019). Various authors reported on the diversity of endophytic fungi derived from medicinal plants. However, as of now, no data is available on fungal diversity

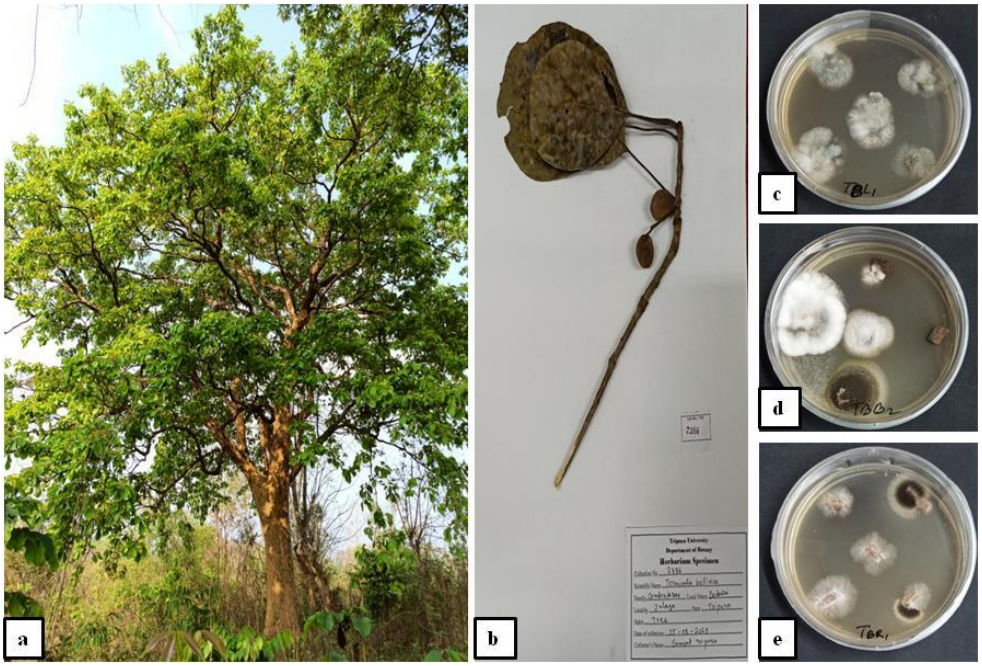


**Figure 2.** *Terminalia bellirica*. a. Natural habitat of the growing plant, b. Herbarium specimen (No.TUH-2386). Emergence colonies of endophytic fungi from different tissues of *T. bellirica* (c. Leaves, d. Bark and e. Root).

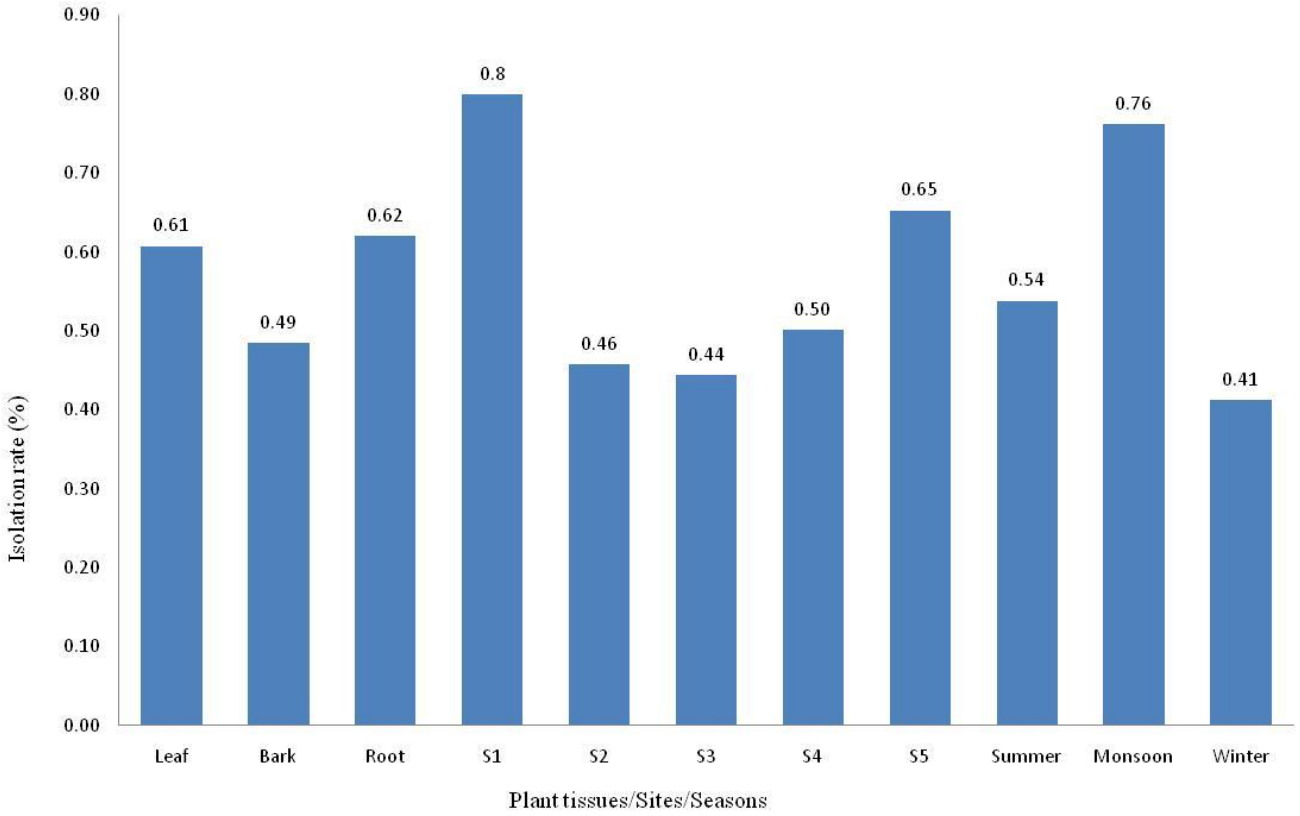


**Figure 3**. Isolation rate of endophytic fungi associated with *T. bellirica* across the tissues, site and seasons.

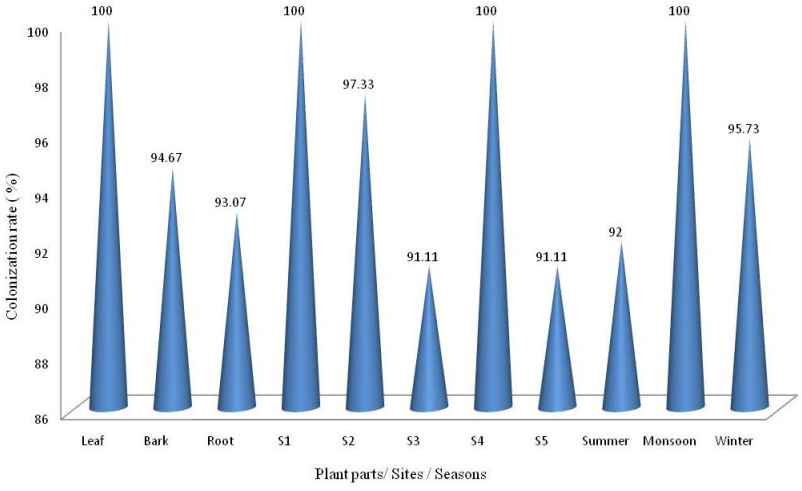


**Figure 4.** Colonization rate of endophytic fungi associated with *T. bellirica* across the tissues, site and seasons.

whereas bark tissues were cut into short pieces (5-6 cm long) and then the roots were excised into 4-5 cm long using the sterile blade (Surynarayanan and Vijaykrishna, 2001) with minor modifications. The excised plant tissues were placed onto a Malt Extract Agar (MEA) medium supplemented with antibiotic streptomycin (500 mg $L^{-1}$) and subsequently sealed with parafilm. The petri plates were incubated at 28±1°C for 3-5 days and regularly observed for fungal growth. Individual hyphal tips that emerged from the edges of each plate were transferred separately onto fresh MEA plates. The pure fungal cultures were transferred onto the MEA slant and used for further experiments. The pure endophytic fungal culture growing individually onto the fresh MEA medium was picked up using sterile needles and observed on the slide with the help of lactophenol cotton blue reagent under the Leica DM 750 microscope at 20X, 40X, and 100X magnifications. The isolates were identified based on their morphological and microscopic features, such as colony colour, texture, growth rate, hyphal structure, pigmentations, fungal spore morphology, and reproductive structures with the help of standard manual and texts (Ellis, 1971; Domsch et al., 1980; Watanabe, 2002).

### *2.3 Statistical analysis*

The collected data was subjected to statistical analysis to understand the diversity of endophytic fungi associated with *T. bellirica*. The colonization rate, isolation rate, colonization frequency, and relative species frequency were calculated as per the formulae given below. In addition, the diversity indices including Shannon index (*H'*), Simpson's dominance (*D*), Simpson's diversity index (1-*D*), Fisher's alpha diversity index (*a*), Berger-Parker dominance (*B*), Brillouin index (*HB*) and Pilou evenness (*J*) were determined using R statistical software version 4.2.0 (R Core Team, 2022) to figure out the diversity of the endophytic fungal isolates between three different tissues, sites and three seasons.

Colonization rate (CR %) (Petrini et al., 1982)
CR % = (Total number of plant-tissue segments infected by one or more fungi) / (Total number of inoculated segments) ×100

Isolation rate (IR) (Wang and Guo, 2007)
IR = (Number of isolates obtained from plant tissue segments) / (Total number of segments inoculated)

Colonization frequency (CF %) (Fisher and Petrini, 1987)
CF % = (Number of segments colonized by each fungus) / (Total number of segments inoculated) × 100

Relative frequency (RF %) (Huang et al., 2008)
RF % = (Number of isolates of a species) / (Total number of isolates) × 100

## 3. Results

### *3.1 Isolation and identification of endophytic fungi*

A total of 643 endophytic isolates were obtained from 1125 plant segments of *T. bellirica* collected from five different localities. Of these, 228, 182, and 233 isolates were recovered from leaves, barks, and roots, respectively (Table 3). The maximum colonization rate occurred in leaf tissues (100%), followed by barks (94.67%) and roots (93.07%). The isolation rate of fungal isolates was found maximum in the root (0.62), followed by leaves (0.61) and barks (0.49). A significant effect of host tissues was noticed on the colonization of endophytic fungi (Table 3).

Plant samples collected from Suryamaninagar (S1) have shown maximum recovery of endophytes (180 isolates) followed by Debasthal (S5) (147), Hathai Kotor (S4) (113), Bishalgarh (S2) (103), and the lowest was from Ampinagar (S3) (100) (Figure 2). The maximum colonization rate occurred in S1and S4 (100%) followed by S2 (97.33%), and least was recorded in S3 and S5 (91.11%). The isolation rate was maximum in S1 (0.80), whereas the lowest was recorded in S3 (0.44). The maximum endophytic fungal isolates were recovered during the monsoon season (286) followed by summer (202) and the lowest were observed in the winter season (155). The highest colonization rate was during monsoon followed by winter and summer; however, the maximum isolation rate was recorded in monsoon (0.76) followed by summer (0.54) and winter (0.41) respectively (Figure 3 and 4).

From *T. bellirica*, 26 endophytic fungal species were identified, belonging to 14 genera, 12 families, and 4 classes, along with 4 sterile mycelia morphotypes. A total of 26 endophytic fungal isolates were obtained along with four non-sporulating forms (Table 2). Among the isolates, twenty-two fungal isolates were obtained from leaves including the three non-sporulating forms; twenty fungal isolates were recovered from barks with the three non-sporulating forms, whereas root harbored twenty-six fungal isolates including the four non-sporulating forms. Out of these, Ascomycota was found to be dominant (93%), followed by non-sporulating forms (5%) and Mucoromycota (2%) (Figure 6). The isolated endophytic fungi were divided into five major classes namely Euromycetes, Dothideomycetes, Sordariomycetes, Mucoromycetes, and Sterile mycelia, and the maximum isolates belonged to Sordariomycetes (47%) (Figure 7).

The most fungal genera obtained from the *T. bellirica* were as follows: *Aspergillus niger*, *Alternaria alternata*, *Aspergillus flavus*, *Aspergillus fumigatus*, *Chaetomium* sp., *Colletotrichum gloeosporioides*, *Corynespora torulosa*, *Diaporthe* sp., *Fusarium decemcellulare*, *Fusarium falciforme*, *Fusarium oxysporum*, *Fusarium solani*, *Lasiodiplodia theobromae*, *Mucor* sp., *Nigrospora* sp., *Penicillium exsudans*, *Penicillium* sp. 1, *Penicillium* sp. 2, *Pestalotiopsis* sp., *Talaromyces australis*, *Trichoderma harzianum*, *Trichoderma* sp., and the sterile mycelia which did not sporulate (Figure 5). *Aspergillus niger, Colletotrichum gloeosporioides, Corynespora torulosa, Lasiodiplodia theobromae, Penicillium exsudans* were the most dominant species of endophytic fungi associated with *T. bellirica*.

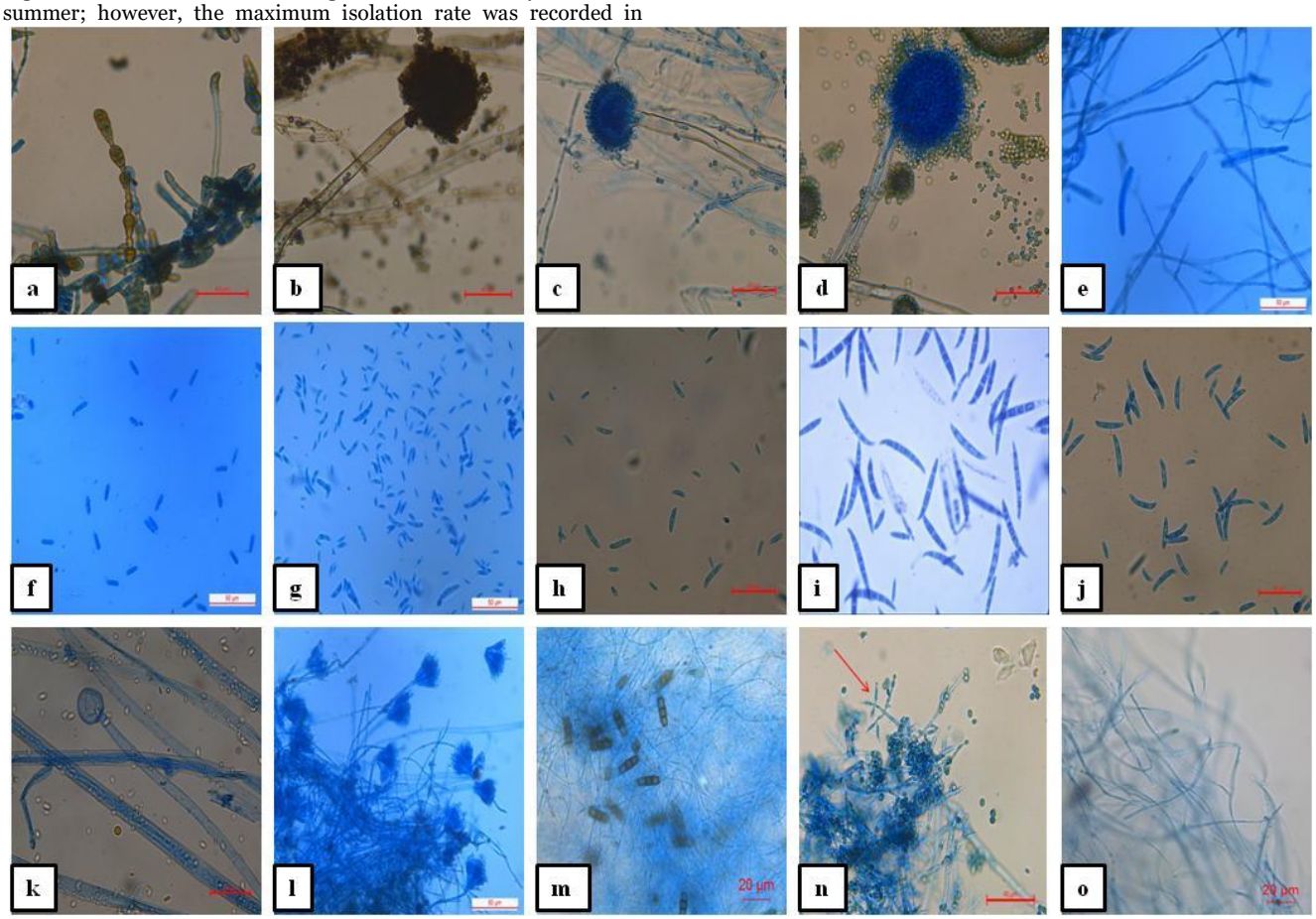


**Figure 5.** Endophytic fungus isolated from three different tissues viz. leaf, bark, root of *T. bellirica*. a. *Alternaria alternata*, b. *Aspergillus niger*, c. *Aspergillus flavus*, d. *Aspergillus fumigatus*, e. *Corynespora torulosa*, f. *Colletotrichum gloeosporioides*, g. *Fusarium falciforme*, h. *Fusarium solani*, i. *Fusarium decemcellulare*, j. *Fusarium oxysporum*, k. *Mucor* sp., l. *Penicillium* sp. 2, m. *Pestalotiopsis* sp., n. *Trichoderma* sp., o. Non-sporulating groups I. Scale bar: a-d, h, j, k, and n = 40µm; e-g, i, l, m and o = 20µm.

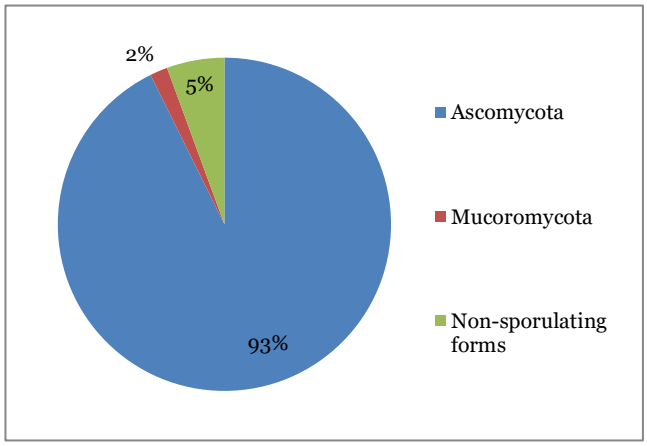


Figure 6. Occurrence of endophytic fungal phylum associated with *T. bellirica*.

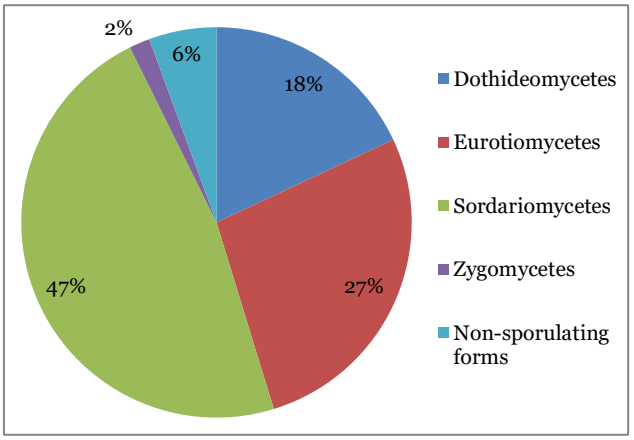


Figure 7. Pie chart showing the different classes of endophytic fungi isolated from *T. bellirica*.

*3.2. Effect of colonization frequency on tissues, sites and seasons*

The results showed that the season affected the colonization of endophytic fungi communities in the sampling sites (Table 4). During the summer season, *Aspergillus fumigatus, Nigrospora* sp., non-sporulating groups (NS Gr.) I, NS Gr. II and NS Gr. IV were found confined to one site, whereas *Diaporthe* sp., *Fusarium falciforme, Penicillium* sp. 2, *Pestalotiopsis* sp., and *Talaromyces australis* were observed in two sites. However, *Corynespora torulosa* and *Lasiodiplodia theobromae* exist in all five sites (Table 5). In the case of monsoon season, *Aspergillus niger* and NS Gr. III occurred only at one site, whereas *Chaetomium* sp., *Nigrospora* sp., *Penicillium* sp. 3, NS Gr. II, NS Gr. IV was found in two sites. In addition, *Colletotrichum gloeosporioides, Corynespora torulosa, Fusarium oxysporum, Fusarium solani, Lasiodiplodia theobromae, Trichoderma harzianum* are present in all the study sites (Table 6). During the winter season, *Aspergillus flavus, Mucor* sp., *Nigrospora* sp., *Penicillium* sp. 3, *Pestalotiopsis* sp. *Talaromyces australis, Trichoderma* sp., NS Gr. II, NS Gr. III were present at one site, whereas *Chaetomium* sp., *Fusarium oxysporum, Fusarium solani, Fusarium falciforme,* NS Gr. I was recorded on two sites. But *Colletotrichum gloeosporioides* and *Diaporthe* sp. were present in all study sites (Table 7). The present study showed that season influenced the composition of endophytic fungi within the host plants. Therefore, some endophytic fungal taxa were reported in only one or two seasons. For instance, *Penicillium* sp. 3 was exclusively reported during winter, whereas *Alternaria alternata* and NS Gr. IV were recorded in the summer and winter seasons and the rest of the isolates were reported in all the seasons. None of the *Fusarium oxysporum, Penicillium* sp. 3 and NS Gr. IV was obtained from the leaves and barks, whereas *Fusarium falciforme* was absent in the leaf sample. However, *Mucor* sp., *Nigrospora* sp., *Pestalotiopsis* sp. was devoid of bark.

Overall, the total colonization frequency was recorded maximum in the monsoon season, followed by summer, and winter. The overall percent of colonization frequency (CF) was shown by *Colletotrichum gloeosporioides*, *Aspergillus niger, Corynespora torulosa,* and non-sporulating mycelia IV was the lowest. During the summer season, the maximum colonization frequency was observed in *Aspergillus niger, Colletotrichum gloeosporioides, Lasiodiplodia theobromae* and the lowest occurred in *Nigrospora* sp., NS Gr. II and NS Gr. IV (Table 5). In monsoon, however, the colonization frequency was highest in *Colletotrichum gloeosporioides, Fusarium decemcellulare, and Penicillium* sp. 2, and the lowest was observed in NS Gr. III (Table 6). During the winter season, the highest colonization frequency was noticed in *Colletotrichum gloeosporioides, Corynespora torulosa Diaporthe* sp., and the lowest occurred in *Mucor* sp., *Pestalotiopsis* sp., *Talaromyces australis*, and NS Gr. III (Table 7). The maximum relative frequency (RF) was recorded in *Colletotrichum gloeosporioides*, followed by *Aspergillus niger*, *Corynespora torulosa,* and the lowest RF value was found in NS Gr. IV (Table 8).

*3.3. Diversity analysis of endophytic fungi*

The endophytic fungal diversity varied significantly among different tissue types (Table 9). The Shannon diversity index, Simpson's (1-*D*), Pilou evenness (*J*), Fisher alpha, and Brillouin diversity index were highest in the root tissues followed by leaf tissues, and the lowest was observed in the bark. A notable influence of season on the endophytic fungal diversity was recorded. It was observed that the Fisher alpha diversity was higher during the winter season compared to the summer season, whereas the Shannon, Simpson, Pilou evenness (*J*), and Dominance (D) data showed higher values during the summer. Significant variation was also observed during the diversity analysis considering several locations of Tripura, Northeast, India (Table 9).

## 4. Discussion

In the present study a greater diversity of endophytic fungi was observed in different plant parts of *Terminalia bellirica,* a medicinally important plant collected from different locations of Tripura, Northeast-India. Isolation of endophytic fungi from medicinal plants gives an idea about their distribution in different tissues irrespective of geographic locations and various seasonal climatic conditions. This study recorded a higher endophytic fungal composition recovery from leaf tissues compared to bark and root tissues, which is in correspondence with the previous findings (Gond et al., 2012; Yu et al., 2018; Crasta and Anandrao, 2024). Higher colonization of endophytes in the leaf tissues could be due to exposure to wider surface area, rich nutrition, thin walls of leaves to external environment and also higher stomata rate on the abaxial surface that allow the fungal aerospores to enter inside (Lebron et al., 2002; Gond et al., 2012; Al-Harthi et al., 2023).
Our findings indicated that geographical location of *T. bellirica* influences the composition of endophytic fungi (Table 2). Several research studies have demonstrated that the degree of colonization may be influenced by site-specific factors (Carroll, 1995). The recovery of the endophytic fungal population was significantly affected by the sampling seasons in this study. The present study showed that the season influenced the composition of fungal endophytes in *T. bellirica*. Different selection pressures like pH, temperature and salinity acting on endophytes in different seasons within plant tissues are the primary determiners of the fluctuation of the species composition (Rodriguez et al., 2008; Kamalraj and Muthumary, 2013).

Most of the isolates belong to the phylum Ascomycota. The study conducted by several researchers also reported similar findings that most of the fungal isolates belong to the class Sordariomycetes and phylum Ascomycota (Gopane et al., 2021; Jahromi et al., 2021; Hatamzadeh et al., 2023; Crasta and Anandrao, 2024; Nongthombam et al., 2024). Vemireddy et al (2020) reported about rich fungal species colonized different tissues of *T. bellirica* and the fungal isolates represented in our study were also similar to their study. Some of the fungal isolates like *Colletotrichum*

*gloeosporioides*, *Lasiodiplodia*, and *Pestalotiopsis* were reported for the first time from *T. bellirica* that has been reported in other *Terminalia* species (Duong et al., 2006).

The variation in colonization frequency was also recorded across different collection sites. This variability may be due to the environmental attributes of the collection sites (Yadav et al., 2016). The distances between locations are the driving factor for increasing the likelihood of recovering diverse endophytic fungal species (Massimo et al., 2015). Several studies have shown that the seasons directly affect the composition of fungal communities and their colonization patterns (Kumar and Prasher, 2022). Our results showed that the fungal endophytes have recorded maximum during the monsoon season. It was reported that high moisture, temperature, and fluctuation of secondary metabolites expand the growth and dispersal of endophytic fungi spores during the monsoon seasons (Mishra et al., 2012; Fang et al., 2013). Tejesvi et al (2005) in their study on *Terminalia arjuna* reported about the rich endophytic fungal diversity during the monsoon season. On the contrary, several studies have noticed higher endophytic fungal diversity was in the winter season compared to rainy and summer seasons (Fang et al., 2013). In addition, a lower annual rainfall and temperature may influence the colonization of endophytes in host tissues (Sadeghi et al., 2019).
The results on diversity indices indicated that the seasons, tissues and sites affected the colonization and distribution of fungal endophytes associated with *T. bellirica*. The Simpson's diversity and Shannon-Wiener indices of endophytic fungi recovered from *Cymbidium aloifolium* have recorded the highest diversity values in root tissues that suggest the diversity of endophytic fungi varies within the host plant tissues and sites (Nisa et al., 2015). The variation in the endophytic diversity among sampling locations could be due to differences in micro-environment conditions, soil pH, host attributes, and agronomic practices at the studied sites (Jan et al., 2022). Fungal taxa spatially restricted distribution suggests that endophytic communities are spatially structured (Sadeghi et al., 2019). Environmental elements including temperature, humidity, and ecological niches impact endophyte variation and play a crucial role in the spread and success of endophytic fungal spore germination (Shannon and Weaver, 1963).

## 5. Conclusion

The present study revealed that the *T. bellirica* plant harbored diverse endophytic fungi. It was observed that different tissue types, host plant locations, and seasons influenced the endophytic fungal composition and diversity. A total of 643 endophytic fungal isolates were isolated from different tissues of *T. bellirica* across summer, monsoon, and winter seasons. The fungal isolates were identified using macroscopic and microscopic techniques. The most dominant species among the isolates were *Aspergillus niger, Colletotrichum gloeosporioides, Corynespora torulosa, Lasiodiplodia theobromae,* and *Penicillium exsudans.* The majority of the isolated ones belonged to the class Sordariomycetes of the phylum Ascomycota. Tissue specificity was observed in the endophytic fungi colonization on the host tissues. The maximum colonization of endophytic fungi was detected in Suryamaninagar (S1) as compared to the other study sites. During the summer season, the overall maximum colonization frequency was shown by *Aspergillus niger*; whereas *Colletotrichum gloeosporioides* was observed highest during the monsoon and winter seasons. The diversity indices showed that the isolated endophytic fungi were highest during the monsoon season and lowest during the winter. This intricate web of interactions between the endophytic fungi and the host plant and/or the results of these interactions may be helpful in enhancing production and sustainability of *T. bellirica*.

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**Authors' contributions**
ST and AKS perceived the idea and designed the experiments. ST, RS and PD conducted the field survey for sample collections. ST performed the experiments and prepared the initial manuscript. SP conducted the data analysis. PD, SP and AKS edited the draft and finalized the manuscript. All authors have read and approved the final manuscript.

**Conflicts of interests**
The authors clearly state that there is no conflict of interest.

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**Table 1.** Details of medicinal plant collected from the Tripura, India.

| Sl No. | Scientific name | Plant family | Plant parts | Voucher specimen | Uses | References |
|---|---|---|---|---|---|---|
| 1. | *Terminalia bellirica* (Gaertn.) Roxb. | Combretaceae | Leaves, barks, and roots | TUH-2386 | Lower cholesterol and glucose levels, treat respiratory disorders. It is also used for good antioxidant, biological, pharmaceutical agents and synthesis of nanoparticles. | Latha and Daisy, 2011; Nampoothiri et al., 2011; Akhter et al., 2019 |

**Table 2.** Collection ID, GPS coordinates, soil pH, soil temperature and soil moisture of the sampling sites in Tripura, India.

| Location | Suryamaninagar (S1) | Bishalgarh (S2) | Ampinagar (S3) | Hathai Kotor (S4) | Debasthal (S5) |
|---|---|---|---|---|---|
| Longitude | 23°45'45"N | 23°40'06"N | 23°40'33"N | 23°48'56"N | 24°19'13"N |
| Latitude | 91°15'51"E | 91°18'11"E | 91°37'54"E | 91°34'48"E | 92°03'36"E |
| Altitude (m) | 41 | 54 | 64 | 121 | 94 |
| Soil pH | 7 | 6.8 | 6.5 | 7.5 | 7.5 |
| Soil temperature | 26.5°C | 28°C | 22°C | 27°C | 20°C |
| Soil moisture | 0.06 | 0.08 | 0.07 | 0.09 | 0.07 |
| *Forest types | Moist deciduous mixed forest | Sal forest | Moist deciduous mixed forest | Garjan forest | Evergreen forest |

***Forest types** – Source: India State of Forest Report (ISFR 2021).

**Table 3.** Isolation rate (IR) and percentage of colonization rate (CR) of *T. bellirica*.

| | No. of segments inoculated | No. of segments infected | No. of isolates obtained | IR | CR % |
|---|---|---|---|---|---|
| Leaf | 375 | 375 | 228 | 0.61 | 100 |
| Bark | 375 | 355 | 182 | 0.49 | 94.67 |
| Root | 375 | 349 | 233 | 0.62 | 93.07 |
| S1 | 225 | 225 | 180 | 0.80 | 100 |
| S2 | 225 | 219 | 103 | 0.46 | 97.33 |
| S3 | 225 | 205 | 100 | 0.44 | 91.11 |
| S4 | 225 | 225 | 113 | 0.50 | 100 |
| S5 | 225 | 205 | 147 | 0.65 | 91.11 |
| Summer | 375 | 345 | 202 | 0.54 | 92 |
| Monsoon | 375 | 375 | 286 | 0.76 | 100 |
| Winter | 375 | 359 | 155 | 0.41 | 95.73 |

**Note:** S1- Suryamaninagar, S2- Bishalgarh, S- Ampinagar, S4- Hathai Kotor, S5- Debasthal.

**Table 4.** Occurrence of endophytic fungi of *T. bellirica* collected from different tissues, sites and seasons.

| Fungal isolates | L | B | R | S1 | S2 | S3 | S4 | S5 | Summer | Monsoon | Winter |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Alternaria alternata* | + | + | + | + | + | + | + | + | + | + | - |
| *Aspergillus flavus* | + | + | + | + | + | - | + | + | + | + | + |
| *Aspergillus fumigatus* | + | + | + | + | + | + | + | + | + | + | + |
| *Aspergillus niger* | + | + | + | + | + | + | + | + | + | + | + |
| *Chaetomium* sp. | + | + | + | + | + | + | + | + | + | + | + |
| *Colletotrichum gloeosporioides* | + | + | + | + | + | + | + | + | + | + | + |
| *Corynespora torulosa* | + | + | + | + | + | + | + | + | + | + | + |
| *Diaporthe* sp. | + | + | + | + | + | + | + | + | + | + | + |
| *Fusarium decemcellulare* | + | + | + | + | + | + | + | + | + | + | + |
| *Fusarium falciforme* | - | + | + | + | + | + | + | + | + | + | + |
| *Fusarium oxysporum* | - | - | + | + | + | + | + | + | + | + | + |
| *Fusarium solani* | + | + | + | + | + | + | + | + | + | + | + |
| *Lasiodiplodia theobromae* | + | + | + | + | + | + | + | + | + | + | + |
| *Mucor* sp. | + | - | + | - | + | - | + | + | + | + | + |
| *Nigrospora* sp. | + | - | + | - | + | - | - | + | + | + | + |
| *Penicillium exsudans* | + | + | + | + | + | + | + | + | + | + | + |
| *Penicillium* sp. 1 | + | + | + | + | + | + | - | + | + | + | + |
| *Penicillium* sp. 2 | - | - | + | + | - | - | - | + | - | + | + |
| Pestalotiopsis sp. | + | - | + | + | + | + | + | - | + | + | + |
| *Talaromyces australis* | + | + | + | + | - | + | + | + | + | + | + |
| *Trichoderma harzianum* | + | + | + | + | + | + | + | + | + | + | + |
| *Trichoderma* sp. | + | + | + | + | - | + | + | + | + | + | + |
| NS Gr. I | + | + | + | + | + | + | + | + | + | + | + |
| NS Gr. II | + | + | + | + | - | + | - | - | + | + | + |
| NS Gr. III | + | + | + | + | + | + | + | + | + | + | + |
| NS Gr. IV | - | - | + | + | - | - | + | - | + | + | - |

**Note:** L= Leaves, B= Bark, R= Root, S1- Suryamaninagar, S2- Bishalgarh, S3- Ampinagar, S4- Hathai Kotor, S5- Debasthal. NS Gr. = Non-sporulating groups.

**Table 5.** Percent (CF) Colonization frequency of endophytic fungi in different tissues of *Terminalia bellirica* in summer season.

| Fungal isolates | S1 | | | S2 | | | S3 | | | S4 | | | S5 | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L | B | R | L | B | R | L | B | R | L | B | R | L | B | R | CF |
| *Alternaria alternata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 8 | 0 | 4 | 16 |
| *Aspergillus flavus* | 0 | 0 | 4 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 20 |
| *Aspergillus fumigatus* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| *Aspergillus niger* | 4 | 12 | 20 | 0 | 0 | 0 | 8 | 4 | 0 | 4 | 20 | 8 | 4 | 28 | 12 | 124 |
| *Chaetomium* sp. | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 4 | 0 | 8 | 0 | 0 | 24 |
| *Colletotrichum gloeosporioides* | 20 | 24 | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 20 | 4 | 0 | 4 | 8 | 0 | 100 |
| *Corynespora torulosa* | 4 | 0 | 0 | 20 | 0 | 0 | 4 | 0 | 8 | 8 | 8 | 0 | 12 | 0 | 0 | 64 |
| *Diaporthe* sp. | 0 | 0 | 0 | 0 | 8 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 |
| *Fusarium decemcellulare* | 0 | 16 | 4 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 32 |
| *Fusarium falciforme* | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 16 |
| *Fusarium oxysporum* | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 4 | 0 | 0 | 16 | 0 | 0 | 0 | 24 |
| *Fusarium solani* | 8 | 8 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 32 |
| *Lasiodiplodia theobromae* | 0 | 0 | 8 | 8 | 20 | 0 | 8 | 0 | 0 | 8 | 0 | 4 | 12 | 0 | 16 | 84 |
| *Mucor* sp. | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 4 | 0 | 0 | 12 | 0 | 0 | 20 |
| *Nigrospora* sp. | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| *Penicillium exsudans* | 12 | 0 | 0 | 0 | 0 | 8 | 0 | 8 | 4 | 0 | 0 | 12 | 0 | 0 | 0 | 44 |
| *Penicillium* sp. 1 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| *Penicillium* sp. 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Pestalotiopsis* sp. | 8 | 0 | 0 | 12 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 28 |
| *Talaromyces australis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 8 |
| *Trichoderma harzianum* | 0 | 8 | 24 | 0 | 0 | 12 | 0 | 0 | 4 | 0 | 8 | 8 | 0 | 0 | 8 | 72 |
| *Trichoderma* sp. | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 4 | 0 | 0 | 16 | 28 |
| NS Gr. I | 8 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 |
| NS Gr. II | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| NS Gr. III | 0 | 0 | 4 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 16 |
| NS Gr. IV | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| Total | 72 | 88 | 72 | 40 | 48 | 60 | 28 | 16 | 48 | 52 | 48 | 56 | 80 | 36 | 64 | 808 |

**Note:** L= Leaves, B= Bark, R= Root, S1- Suryamaninagar, S2- Bishalgarh, S- Ampinagar, S4- Hathai Kotor, S5- Debasthal. NS Gr. = Non-sporulating groups.

**Table 6.** Percent (CF) Colonization frequency of endophytic fungi in different tissues of *Terminalia bellirica* in monsoon season.

| Fungal isolates | S1 | | | S2 | | | S3 | | | S4 | | | S5 | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L | B | R | L | B | R | L | B | R | L | B | R | L | B | R | CF |
| *Alternaria alternata* | 0 | 4 | 0 | 0 | 0 | 8 | 0 | 0 | 8 | 0 | 8 | 0 | 0 | 0 | 0 | 28 |
| *Aspergillus flavus* | 0 | 4 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 8 | 28 |
| *Aspergillus fumigatus* | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 16 |
| *Aspergillus niger* | 0 | 8 | 12 | 0 | 4 | 8 | 0 | 0 | 8 | 0 | 0 | 4 | 0 | 12 | 16 | 72 |
| *Chaetomium* sp. | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 16 |
| *Colletotrichum gloeosporioides* | 28 | 24 | 0 | 12 | 0 | 8 | 16 | 0 | 12 | 0 | 8 | 8 | 16 | 24 | 0 | 156 |
| *Corynespora torulosa* | 32 | 0 | 12 | 0 | 0 | 4 | 4 | 0 | 0 | 4 | 0 | 0 | 28 | 0 | 0 | 84 |
| *Diaporthe* sp. | 20 | 0 | 4 | 0 | 0 | 0 | 4 | 0 | 0 | 8 | 0 | 4 | 20 | 0 | 4 | 64 |
| *Fusarium decemcellulare* | 4 | 28 | 4 | 0 | 0 | 0 | 8 | 4 | 0 | 8 | 4 | 0 | 0 | 36 | 0 | 96 |
| *Fusarium falciforme* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 8 | 12 |
| *Fusarium oxysporum* | 0 | 0 | 4 | 0 | 0 | 8 | 0 | 0 | 4 | 0 | 0 | 16 | 0 | 0 | 4 | 36 |
| *Fusarium solani* | 0 | 0 | 4 | 0 | 0 | 4 | 0 | 0 | 4 | 0 | 0 | 4 | 0 | 0 | 12 | 28 |
| *Lasiodiplodia theobromae* | 4 | 32 | 4 | 4 | 0 | 0 | 0 | 0 | 4 | 12 | 0 | 0 | 16 | 0 | 0 | 76 |
| *Mucor* sp. | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 8 | 20 |
| *Nigrospora* sp. | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 12 |
| *Penicillium exsudans* | 8 | 12 | 4 | 0 | 0 | 0 | 8 | 16 | 4 | 0 | 16 | 8 | 0 | 0 | 0 | 76 |
| *Penicillium* sp. 1 | 12 | 4 | 0 | 16 | 20 | 20 | 12 | 0 | 4 | 0 | 0 | 0 | 0 | 4 | 0 | 92 |
| *Penicillium* sp. 2 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 12 |
| *Pestalotiopsis* sp. | 0 | 0 | 0 | 0 | 0 | 4 | 8 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 20 |
| *Talaromyces australis* | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 8 | 24 |
| *Trichoderma harzianum* | 0 | 8 | 0 | 12 | 0 | 0 | 20 | 8 | 0 | 0 | 16 | 0 | 0 | 8 | 12 | 84 |
| *Trichoderma* sp. | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 4 | 4 | 16 |
| NS Gr. I | 4 | 12 | 0 | 0 | 0 | 4 | 4 | 0 | 4 | 0 | 0 | 4 | 0 | 0 | 0 | 32 |
| NS Gr. II | 4 | 0 | 12 | 0 | 0 | 0 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 28 |
| NS Gr. III | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 4 |
| NS Gr. IV | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 12 |
| Total | 120 | 140 | 88 | 44 | 24 | 84 | 88 | 40 | 68 | 32 | 56 | 80 | 88 | 88 | 104 | 1144 |

**Note:** L= Leaves, B= Bark, R= Root, S1- Suryamaninagar, S2- Bishalgarh, S- Ampinagar, S4- Hathai Kotor, S5- Debasthal. NS Gr. = Non-sporulating groups.

**Table 7.** Percent (CF) Colonization frequency of endophytic fungi indifferent tissues of *Terminalia bellirica* in winter season.

| Fungal isolates | S1 | | | S2 | | | S3 | | | S4 | | | S5 | | | Total CF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L | B | R | L | B | R | L | B | R | L | B | R | L | B | R | |
| *Alternaria alternata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Aspergillus flavus* | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| *Aspergillus fumigatus* | 0 | 0 | 4 | 0 | 4 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 12 |
| *Aspergillus niger* | 8 | 0 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 4 | 0 | 0 | 36 |
| *Chaetomium* sp. | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 12 |
| *Colletotrichum gloeosporioides* | 16 | 0 | 0 | 12 | 20 | 0 | 16 | 0 | 0 | 20 | 0 | 0 | 4 | 0 | 4 | 92 |
| *Corynespora torulosa* | 0 | 8 | 4 | 0 | 20 | 0 | 0 | 0 | 0 | 4 | 12 | 8 | 12 | 0 | 4 | 72 |
| *Diaporthe* sp. | 8 | 0 | 4 | 20 | 0 | 0 | 4 | 0 | 0 | 16 | 0 | 0 | 4 | 0 | 8 | 64 |
| *Fusarium decemcellulare* | 8 | 0 | 0 | 0 | 0 | 8 | 0 | 4 | 12 | 0 | 12 | 0 | 0 | 0 | 0 | 44 |
| *Fusarium falciforme* | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 8 |
| *Fusarium oxysporum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 8 | 20 |
| *Fusarium solani* | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 4 | 16 |
| *Lasiodiplodia theobromae* | 8 | 0 | 8 | 0 | 0 | 0 | 8 | 0 | 0 | 8 | 4 | 0 | 0 | 4 | 0 | 40 |
| *Mucor* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 4 |
| *Nigrospora* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 4 | 8 |
| *Penicillium exsudans* | 0 | 0 | 0 | 0 | 0 | 8 | 8 | 16 | 8 | 0 | 4 | 8 | 0 | 8 | 0 | 60 |
| *Penicillium* sp. 1 | 0 | 4 | 0 | 0 | 0 | 0 | 20 | 0 | 4 | 0 | 0 | 0 | 12 | 0 | 0 | 40 |
| *Penicillium* sp. 2 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| *Pestalotiopsis* sp. | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| *Talaromyces australis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 4 |
| *Trichoderma harzianum* | 0 | 4 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 28 |
| *Trichoderma* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 |
| NS Gr. I | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 4 | 16 |
| NS Gr. II | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| NS Gr. III | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| NS Gr. IV | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 52 | 20 | 68 | 40 | 44 | 28 | 68 | 20 | 24 | 52 | 40 | 36 | 56 | 20 | 52 | 620 |

**Note:** L= Leaves, B= Bark, R= Root, S1- Suryamaninagar, S2- Bishalgarh, S- Ampinagar, S4- Hathai Kotor, S5- Debasthal. NS Gr. = Non-sporulating groups.

**Table 8.** Relative frequency (RF) of endophytic fungi in different sites and seasons of *Terminalia bellirica*

| Fungal isolates | Tissues | | | Locations | | | | | Seasons | | | Total | RF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L | B | R | S1 | S2 | S3 | S4 | S5 | Summer | Monsoon | Winter | | |
| *Alternaria alternata* | 3 | 3 | 5 | 1 | 2 | 2 | 3 | 3 | 4 | 7 | 0 | 11 | 1.71 |
| *Aspergillus flavus* | 2 | 1 | 11 | 7 | 2 | 0 | 1 | 4 | 5 | 7 | 2 | 14 | 2.18 |
| *Aspergillus fumigatus* | 1 | 3 | 5 | 1 | 2 | 4 | 1 | 1 | 2 | 4 | 3 | 9 | 1.40 |
| *Aspergillus niger* | 8 | 24 | 26 | 20 | 3 | 5 | 11 | 19 | 31 | 18 | 9 | 58 | 9.02 |
| *Chaetomium* sp. | 6 | 1 | 6 | 4 | 2 | 1 | 2 | 4 | 6 | 4 | 3 | 13 | 2.02 |
| *Colletotrichum gloeosporioides* | 46 | 33 | 8 | 28 | 18 | 11 | 15 | 15 | 25 | 39 | 23 | 87 | 13.53 |
| *Corynespora torulosa* | 33 | 12 | 10 | 15 | 11 | 4 | 11 | 14 | 16 | 21 | 18 | 55 | 8.55 |
| *Diaporthe* sp. | 27 | 2 | 6 | 9 | 7 | 3 | 7 | 9 | 3 | 16 | 16 | 35 | 5.44 |
| *Fusarium decemcellulare* | 7 | 27 | 9 | 16 | 4 | 7 | 7 | 9 | 8 | 24 | 11 | 43 | 6.69 |
| *Fusarium falciforme* | 0 | 2 | 7 | 1 | 1 | 3 | 1 | 3 | 4 | 3 | 2 | 9 | 1.40 |
| *Fusarium oxysporum* | 0 | 0 | 20 | 1 | 3 | 2 | 11 | 3 | 6 | 9 | 5 | 20 | 3.11 |
| *Fusarium solani* | 7 | 3 | 9 | 6 | 2 | 1 | 1 | 9 | 8 | 7 | 4 | 19 | 2.95 |
| *Lasiodiplodia theobromae* | 24 | 15 | 11 | 16 | 8 | 5 | 9 | 12 | 21 | 19 | 10 | 50 | 7.78 |
| *Mucor* sp. | 4 | 0 | 7 | 0 | 3 | 0 | 3 | 5 | 5 | 5 | 1 | 11 | 1.71 |
| *Nigrospora* sp. | 3 | 0 | 3 | 0 | 2 | 0 | 0 | 4 | 1 | 3 | 2 | 6 | 0.93 |
| *Penicillium exsudans* | 9 | 20 | 16 | 9 | 4 | 18 | 12 | 2 | 11 | 19 | 15 | 45 | 6.998 |
| *Penicillium* sp. 1 | 18 | 9 | 8 | 6 | 14 | 11 | 0 | 4 | 2 | 23 | 10 | 35 | 5.44 |
| *Penicillium* sp. 2 | 0 | 0 | 5 | 3 | 0 | 0 | 0 | 2 | 0 | 3 | 2 | 5 | 0.78 |
| *Pestalotiopsis* sp. | 8 | 0 | 5 | 3 | 6 | 2 | 2 | 0 | 7 | 5 | 1 | 13 | 2.02 |
| *Talaromyces australis* | 1 | 2 | 6 | 1 | 0 | 4 | 1 | 3 | 2 | 6 | 1 | 9 | 1.40 |
| *Trichoderma harzianum* | 8 | 15 | 23 | 11 | 8 | 8 | 8 | 11 | 18 | 21 | 7 | 46 | 7.15 |
| *Trichoderma* sp. | 4 | 4 | 6 | 2 | 0 | 3 | 3 | 6 | 7 | 4 | 3 | 14 | 2.18 |
| NS Gr. I | 6 | 4 | 6 | 9 | 1 | 2 | 1 | 3 | 4 | 8 | 4 | 16 | 2.49 |
| NS Gr. II | 2 | 2 | 6 | 7 | 0 | 3 | 0 | 0 | 1 | 7 | 2 | 10 | 1.56 |
| NS Gr. III | 1 | 0 | 5 | 2 | 0 | 1 | 1 | 2 | 4 | 1 | 1 | 6 | 0.93 |
| NS Gr. IV | 0 | 0 | 4 | 2 | 0 | 0 | 2 | 0 | 1 | 3 | 0 | 4 | 0.62 |
| Total | 228 | 182 | 233 | 180 | 103 | 100 | 113 | 147 | 202 | 286 | 155 | 643 | |

**Note:** L= Leaves, B= Bark, R= Root, S1- Suryamaninagar, S2- Bishalgarh, S- Ampinagar, S4- Hathai Kotor, S5- Debasthal. NS Gr. = Non-sporulating groups.

**Table 9.** The diversity indices of isolated endophytic fungi of *Terminalia bellirica* based on and tissue, location and season.

| Diversity indices | Tissues | | | Locations | | | | | Seasons | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Leaves | Bark | Root | S1 | S2 | S3 | S4 | S5 | Summer | Monsoon | Winter |
| Species richness (*S*) | 22 | 20 | 26 | 24 | 21 | 21 | 22 | 24 | 25 | 26 | 24 |
| Shannon (*H´*) | 2.5887 | 2.4682 | 3.0883 | 2.7857 | 2.6708 | 2.7402 | 2.7162 | 2.8772 | 2.9463 | 2.8262 | 2.7795 |
| Simpson (1-*D*) | 0.8973 | 0.8929 | 0.9455 | 0.9227 | 0.9115 | 0.9168 | 0.9200 | 0.9318 | 0.9349 | 0.9225 | 0.9212 |
| Pilou evenness (*J*) | 0.2974 | 0.3048 | 0.3063 | 0.2851 | 0.2818 | 0.2991 | 0.3102 | 0.2973 | 0.3056 | 0.2910 | 0.2918 |
| Dominance (*D*) | 0.0987 | 0.1021 | 0.0504 | 0.0722 | 0.0796 | 0.0739 | 0.0717 | 0.0618 | 0.0730 | 0.0618 | 0.0728 |
| Fisher alpha (*a*) | 6.0069 | 5.3407 | 7.4966 | 7.4374 | 7.4003 | 8.1068 | 8.1517 | 7.6503 | 7.5111 | 6.9494 | 7.9446 |
| Berger-Parker (*B*) | 0.2018 | 0.1813 | 0.1116 | 0.1556 | 0.1748 | 0.1800 | 0.1327 | 0.1293 | 0.1535 | 0.1364 | 0.1484 |
| Brillouin (*HB*) | 2.4282 | 2.3012 | 2.8863 | 2.5768 | 2.3915 | 2.4416 | 2.4440 | 2.6297 | 2.6249 | 2.7814 | 2.5457 |

**Note:** S1- Suryamaninagar, S2- Bishalgarh, S3- Ampinagar, S4- Hathai Kotor, S5- Debastha

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