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Morphological diversity of *Ganoderma* species and its host trees in Mezam Division, Northwest Region, Cameroon

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ABSTRACT

Ganoderma P. Karst. is a pathogen that causes root and stem rot in trees, ultimately leading to their death. It can be used to treat various conditions of human diseases. This fungal species often grows on economically significant trees. Its morphological' diversity and host range need to be better understood due to their similarity in morphological resemblance. This research aims to identify the phenotypic diversity of *Ganoderma* species and their host trees. Opportunistic sampling was used to collect samples from nine villages in Mezam Division, Northwest Region of Cameroon. Morphological identification of *Ganoderma* species was done based on morphological characters such as colour, length, and width, laccate or non-laccate, the type of basidiocarp, margin shape, microscopical structures, and hyphae. The morphological characters of basidiocarps collected from different host trees revealed eleven distinct *Ganoderma* species, including *Ganoderma applanatum*, *G. australe*, *G. brownii*, *G. cupreum*, G. *gibbosum*, *G. lucidum*, *G. multipileum*, *G. multiplicatum*, *G. orbiforme*, *G. resinaceum* and *G. weberianum*. This study identified nine host tree species. *Ganoderma resinaceum* was host specific to *Elaeis guineensis. G. cupreum* on *Ficus* sp., and *Persea americana*, and *G. orbiforme* on *Cola acuminata. G. multiplicatum*, *G. lucidum*, *G. gibbosum*, and *G. applanatum* had multiple hosts. *Ganoderma* typically grows on dead tree stumps based on host preferences. However, three species were collected from living trees; one on *Albizia adianthifolia* and two on *Persea americana*, confirming their nature as saprophytes and plant pathogens.

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Introduction

The genus *Ganoderma* is a common and widespread Basidiomycota species that can be parasitic and saprobic (Kinge & Mih 2011; Tchotet Tchoumi et al. 2019). These fungi are known for their brownish, woody, or leathery brackets (Gryzenhout et al. 2021). Certain species have been recognized as the causative agents of plant diseases

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(Edy et al. 2022), including root and stem rots, which can lead to the death of significant economic trees like oil palm (*Elaeis guineensis* Jacq.), rubber (*Hevea brasiliensis* (Willd. ex Juss.) Muell. Arg.), tea (*Camellia sinensis* (L.) Kuntze), ornamental plants (Kinge & Mih 2011; Coetzee et al. 2015), and forest trees like *Acacia*, *Albizia*, *Populus*, and *Macadamia* species (Lee and Chang 2016). Most dead woody plants in forests are broken down by *Ganoderma*, making it ecologically significant for decomposition and delignification (Lee & Chang 2016 and having medicinal and cultural values (Bishop et al. 2015). *Ganoderma* growing on *Acacia erioloba* E. Meyer and *Combretum imberbe* var dielsii treats nosebleeds, boosts infant and maternal immunity during gestation, and strengthens infant cranial bones (Ekanjo & Chimwamurombe 2012). *Ganoderma* extract possesses anti-tumor, immune-boosting, antimicrobial, and cardiovascular properties and may have anti-aging effects (Chen and Miles 1996; Mshigeni & Chang 2001; McMeekin 2004; Sun et al. 2006).

Despite taxonomic techniques used to study the genus, knowledge of *Ganoderma* species and other polypores in Africa still needs to be represented in terms of diversity (Kinge & Mih 2014; Tchotet 2020). Many authors have reported several species of *Ganoderma* in Cameroon, including *G. tornatum* (Pers.) Bres. (Turner 1981, Kinge 2012), *G. tropicum* (Jungh.) Bres. (Kinge et al. 2012), *G. hildebrandii* Henn., *G. lucidum* (Curtis) P. Karst. and *G. multiplicatum* (Mont.) Pat. (Nunez & Daniels 1999; Douanla-Meli 2007), *G. resinaceum* Boud, *G. carocalcareus* sp. nov., and *G. australe* (Fr.) Pat. (Douanla-Meli 2007), *G. chalceum* (Cooke) Steyaert, *G. weberianum* (Bres. & Henn.) Steyaert, *G. ryvardense*, *G. cupreum* (Fries) Bres., *G. steyaertanum* B.J.Sm. & Sivasith., *G. zonatum* Murrill, and *G. lobenense* Kinge and Mih sp. Nov (Kinge 2012). Moncalvo and Ryvarden (1997) listed 49 *Ganoderma* species from Africa. Various species have been found and documented in Africa, including *G. tornatum*, *G. hildebrandii*, *G. resinaceum*, *G. carocalcareus*, *G. ryvardense* R.K. Tonjock & A.M. Mih sp. nov. (Turner 1981; Nunez & Daniels 1999; Douanla-Meli & Langer 2009; Kinge 2012), *G. flexipes* Pat., *G. multipileum* Hou, *G. lucidum*, *G. oregonense* Murrill, *G. neojaponicum* Imazeki, *G. lobatum* (Schwein.) G.F. Atk., *G. stipitatum* (Murrill) Murrill, *G. weberianum*, *G. subamboinense* Hennings var. laeuisporum Bazzalo & Wright, *G. martinicense* Welti & Courtec., *G. parvulum* Kiitz. , *G. multiplicatum*, *G. perzonatum* Murrill, *G. steyaertanum* (Cao et al. 2012; Crous et al. 2014), *G. cf. cupreum*, *G. eickeri* Tchotet, M.P.A. Coetzee, Rajchenb. & Jol. Roux, sp. nov., *G. knysnamense* Tchotet, M.P.A. Coetzee, Rajchenb. & Jol. Roux, sp. nov., *G. tsugae* Murrill, *G. wiireonse* (Kadhila-Muandingi 2010, Hamwenye 2020), *G. destructans* M.P.A. Coetzee, Marinc M.J., Wingf, sp. nov., *G. dunense* Tchotet, Rajchenb., & Jol. Roux sp. nov., *G. austroafricanum* Coetzee, M.J. Wingf., Marinc. & Blanchette, *G. enigmaticum* Coetzee, Marinc. & M.J. Wingf. (Tchotet Tchoumi et al. 2018), *G. orbiforme* (Fr.) Ryvarden, *G. gibbosum* (Blume & T. Nees) Pat., *G. sessiliforme* Murrill, Bull, *G. alluaudii* Pat. & Har., *G. amazonense* Weir, *G. australe*, *G. chalceum*, *G. fassii* Steyaert, *G. hoehnelianum* Bres, *G. petchii* (Lloyd) Steyaert, *G. sculpturatus* (Lloyd) Ryvarden, *G. septatum* Steyaert, *G. sublucidum* (Beeli) Steyaert, *G. subresinosum* Murrill, *G. vanmeelii*, and *G. xylonoides* Steyaert, (Rammeloo & Walleyn 1993, Degreef et al. 2016).

Ganoderma is one of the genera with a worldwide distribution (Hapuarachchi et al. 2019), and many authors have identified various hosts of *Ganoderma* in Cameroon, Africa, and the world. Some host trees identified in Cameroon include *Elaeis guineensis*, *Acacia* sp. *Cassia* sp., *Pinus sylvestris* L., *Persea americana* Mil., *Acacia mangium* Willd., *Hevea brasiliensis*, *Erthrophleum guineense* G.Don, *Klainedoxa gabonensis* Pierre ex Engl., *Triplochiton scleroxylon* K. Schum., *Alstonia boonei De Wild.* (Kinge & Mih 2011; Kinge et al. 2015; Tsigain et al. 2022). From South Africa, *Pseudolagarobasidium acaciicola* Ginns, *Olea capensis* L., *Pterocelastrus tricuspidatus* (Lam.) Sond., *Elaeodendron croceum* (Thunb.) DC., *Apodytes dimidiate* (Hochst. ex A.Rich.) Cufod. ex Mendes, *Ocotea bullata* (Burch.) Baill., *Robsonodendron eucleiforme* (Eckl. & Zeyh.) R.H.Archer, *Fagus sylvatica* L., *Jacaranda mimosifolia* D.Don, and *Cassia* spp. were listed as hosts to Ganoderma (Coetzee et al. 2015; Tchoumi et al. 2017; Tchotet Tchoumi et al.2018; Tchoumi et al. 2019). *Baikiaea plurijuga* Harms, *Colophospermum mopane* (J.Kirk ex Benth.), *Combretum* spp., *Croton gratissimus* Burch, *Grewia retinervis* L., *Mundulea sericea* (Willd.) A.Chev., *Pechuel-Loeschea leubuitziae* (Kuntze) O.Hoffm., *Sclerocarya spp. Senegaria erioloba* (E.Mey.) P.J.H.Hurter, *Terminalia* spp., *and Acacia* spp. were reported from Namibia as hosts of this fungal genus (Ise et al. 2011), while in India, *Prosopis cineraria* (L.) Druce. and many forest and fruit trees were also considered host trees (Mawar et al. 2020).

Most reports on the identification of *Ganoderma* species in Cameroon were based solely on morphology but from the publication of Douanla-Meli & Langer (2009), Teke et al. (2018), Kinge (2012), and Kinge et al. (2012). There is a need to get more knowledge on the diversity of *Ganoderma* in the western highlands of Cameroon (Kinge & Mih 2015); as a result, valuable information is required to fill research gaps. Basidiocarps, the sexual structures in *Ganoderma*, typically grow on living or dead tree trunks, with the latter being the more common occurrence or branch of a tree in the form of a bracket (Mawar et al. 2020). Two types of basidiocarps are produced depending on the species: a laccate fruiting body with a shiny upper surface or a non-laccate fruiting body with a dull upper surface (Smith & Sivasithamparam 2000a, Pilotti et al. 2004).

Specialists have faced several controversies while attempting to classify *Ganoderma*, which has made the taxonomy of this species challenging (Moncalvo et al. 1995a). Several species have been misidentified due to taxonomic controversies and inconsistencies under this genus (Mueller et al. 2007) since *Ganoderma* species exhibit significant genetic heterogeneity due to outcrossing and geographical diversity (Miller et al. 1999; Pilotti et al. 2003). The morphology of organisms can vary even within the same species, leading to differences in their physical characteristics. (Hong et al. 2001). Identifying a species can be challenging due to several factors, such as environmental influences, variation, hybridization, and differences in individual morphology (Zheng et al. 2007). Traditional taxonomic methods based on morphology must be more conclusive in establishing a stable classification system for species within a genus (Hseu et al. 1996; Hong et al. 2002). Different mycologists use varying criteria for fungi identification. Some criteria focus on host specificity, geographic distribution, and macro-morphology of basidiomes, while others emphasize spore characteristics (Sun et al. 2006; Ekandjo 2012). This study aims to determine the diverse morphology of *Ganoderma* species and their host trees in the Mezam Division of the Northwest Region in Cameroon.

Materials and Methods

Description of the study area

This research focused on the Mezam Division, located in the Northwest region of Cameroon. Mezam Division is between latitudes 5°04' and 7°05' North and longitudes 9°08' and 11051' East of the Greenwich Meridian (UNDP 1999). The area's population is over 524,127, with a total surface area of 1,841.45 km^2. The study area comprises seven sub-divisions: Bamenda I, Bamenda II, Bamenda III, Bafut, Bali, Santa, and Tubah (Mbangari et al. 2019), and includes nine villages in this sub-division: Mbatu, Mankon, Nkwen, Bambili, Bambui, Bafut, Mendankwe, Nsongwa, and Santa. The study area is illustrated in Figure 1.

Climate dynamic of the seven sub-divisions

The region has a cool, temperate climate, mountainous terrain, and rugged topography. It receives an average rainfall of 2400 mm and has an average temperature range of 15°C to 32°C. This region has two seasons: the rainy season, lasting from March to October, and the dry season, which lasts from November to February (Olayiwola et al. 2011; Mukete et al. 2018).

Sample collection and morphological identification

Samples were collected from forests in the Mezam division between November 2021 and August 2023 using opportunistic sampling. Each sample was snapped from above-ground and below-ground positions, and the geographic coordinates were accurately marked using GPS. Ziplock bags were labeled and used to collect the samples after wrapping them in aluminum foil. Later, the samples were affixed to A4 papers with a ruler beside them, along with pictures. The basidiocarps were oven-dried at a temperature of 35°C. Morphological characters such as the type of basidiocarp (whether it was laccate or non-laccate and whether it was stipitate, sessile, or dimidiate), length and width, concentric zones, margin shape (lobed, rounded/acute), margin colour (brown, white, reddish, etc.), pore colour, and tube colour were recorded. The morphological characters recorded were compared with those of *Ganoderma* species described by various authors (Ryvarden & Johansen 1980; Corner 1983; Ryvarden 1995; Moncalvo & Ryvarden 1997; Ryvarden 2000; Kinge & Mih 2011).

Samples were prepared for micromorphological analyses by slicing thin sections of dried basidiocarps and passing through the hymenium. The sections were mounted in 5% KOH and observed under a compound microscope. Twenty randomly selected basidiospores from each specimen were measured, and ornamentation was noted. To determine the size and shape of basidiospores, their length and width were measured, and the spore length and width (Q) quotient was calculated using the formula Q=L/W. This was done for at least 20 basidiospores from each basidioma, with the mean length and width used for the calculation done using the method by Miettinen & Larsson (2006) with some modifications. Fungal identification was done using taxonomic keys (Zhao et al. 1983). The host trees were identified at the National Herbarium in Yaounde, Cameroon.

Results

Species diversity

Seventy-one *Ganoderma* samples were collected (Table 1). The various host trees of *Ganoderma*, the place of collection, the collection date, and the collection sites' GPS points were noted. Eleven *Ganoderma* species were identified from their morphology which include *G. applanatum*, *G. australe*, *G. brownii*, *G. cupreum*, *G. gibbosum*, *G. lucidum*, *G. multipileum*,

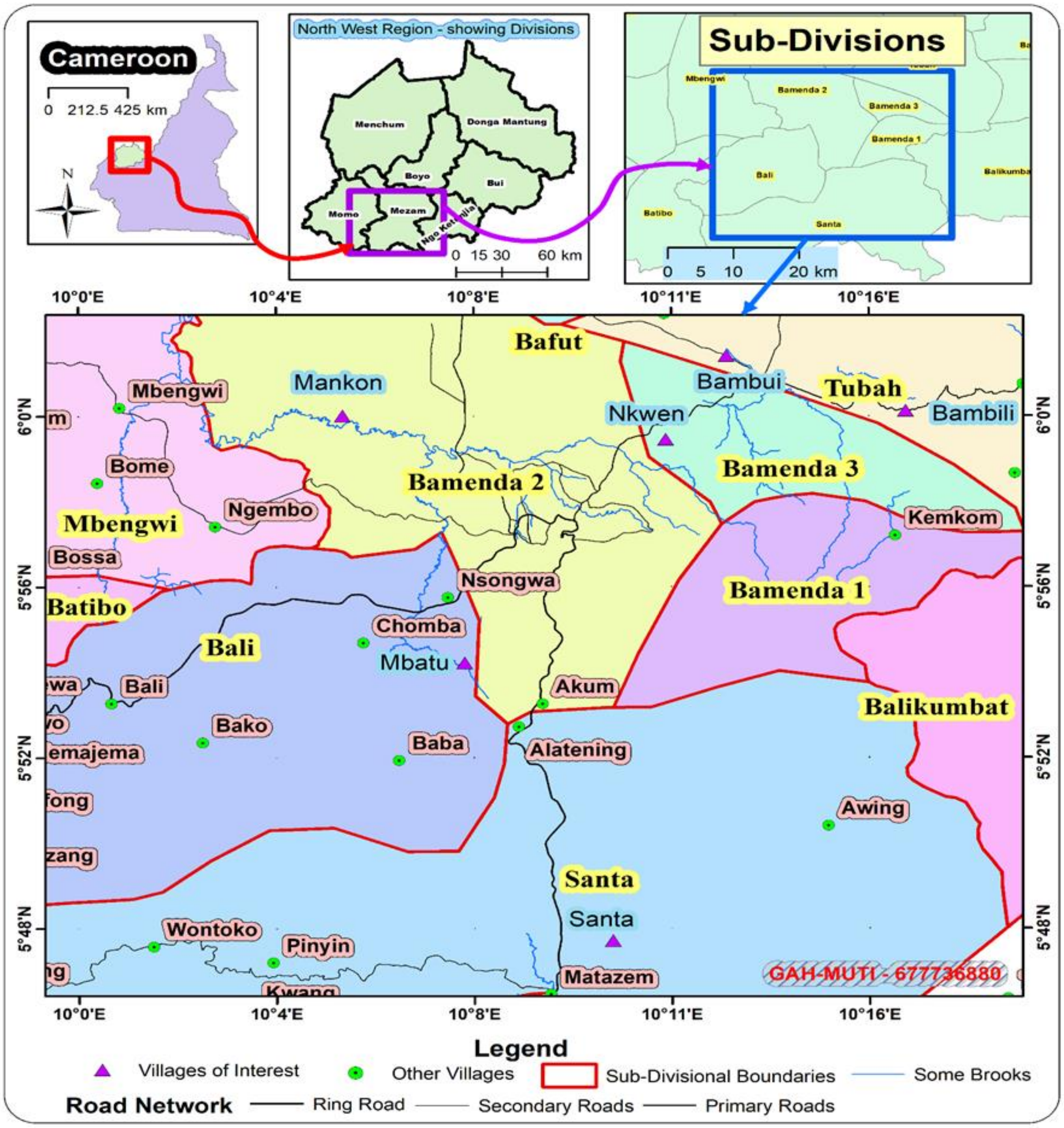

Fig 1. Map of *Ganoderma* species collection sites in Mezam division, Northwest region, Cameroon.

G. multiplicatum, *G. orbiforme G. resinaceum*, and *G. weberianum*.

Natural range and distribution of species of Ganoderma

Nine trees susceptible to *Ganoderma* species, including *Persea americana*, *Elaeis guineensis*, *Mangifera indica* L., *Maesopsis eminii* Engl., *Cola acuminata* (P.Beauv.) Schott & Endl., *Ficus sp.*, *Albizia adianthifolia* (Schumach.) W. Wight, *Croton macrostachyus*, and *Eucalyptus globulus*, Labill. as well as eight unidentified tree stumps, were registered in the study area. Also, from the 71 samples, 11 species were identified, with one that often grows on oil palm and seven on forest trees. January had the highest number of collections (11), while March and July had the least (01) *Ganoderma* species. Collections were made in all seasons, confirming that *Ganoderma* species bear fruit throughout the year. Most of the collections were from dead tree stumps. At the same time, only a few *Ganoderma* species were from living trees, such as *Persea americana* (02) and *Albizia adianthifolia* (01). Table 2 shows the host trees and *Ganoderma* species diversity with the plant families of host trees in the study: Lauraceae, Fabaceae, Anacardiaceae, Moraceae, Malvaceae, Rhamnaceae, Arecaceae, Euphorbiaceae, and Myrtaceae.

Table 1: Species, place of collection, date of collection, G.P.S. points, and host trees of the species identified (Source: This study)

Species no	Village	Date of collection	Longitude	Latitude	Elevation	Host tree
NJM01	Mankon	24/05/22	E010º7'14.8"	N06º00'02.3"	1222m	Dead *Persea americana* stump (Avocado)
NJM03	Mankon	21/11/21	E010º08'54.0"	N06º00'04.1"	1243m	Unidentified dead tree stump
NJM05	Mankon	21/11/21	E010º09'02.3"	N05º59'48.8"	1265m	Dead *Mangifera indica* stump (mango)
NJM07	Mankon	21/11/21	E010º09'02.3"	N05º59'48.8"	1265m	Dead *Mangifera indica* stump (mango)
NJM15	Mankon	24/11/21	E010º06'27.7"	N06º00'29.1"	1263m	Dead *Elaeis guineensis* stump (palm tree)
NJS20	Santa	16/12/21	E010º10'40.9"	N05º51'41.1"	1914m	Dead *Persea americana* stump (Avocado)
NJS23	Santa	16/12/21	E010º10'37.2"	N05º50'36.0"	1921m	Living *Persea americana* stem (Avocado)
NJBM24	Bambili	25/01/22	E010º15'19.7"	N06º01'10.8"	1331m	Dead *Ficus sp.* stump (fig tree)
NJM37	Mankon	22/01/22	E010º08'48.1"	N06º00'12.3"	1251m	Dead *Cola acuminata* stump (Cola tree)
NJM41	Mankon	9/9/2022	E010º08'24.6"	N05º59'29.3"	1217m	Dead *Eucalyptus globulus tree* stump
NJS59	Santa	22/10/22	E010º10'46.1"	N05º52'39.3"	1925m	Unidentified dead tree stump

Table 2: Diversity of host trees, their families, and species of *Ganoderma* in the Mezam division

Hosts	**Family**	***Ganoderma* species**
Ficus sp.	Moraceae	*G. cupreum*
Mangifera indica	Anacardiaceae	*G. weberianum, G. multiplicatum. G. lucidum*
Unidentified dead stump		*G. multipileum*
Persea americana	Lauraceae	*G. multiplicatum, G. brownii, G. applanatum, G. australe*
Albizia adianthifolia	Fabaceae	*G. lucidum, G. applanatum*
Maesopsis eminii	Rhamnaceae	*G. gibbosum*
Cola acuminata stump	Malvaceae	*G. orbiforme*
Elaeis guineensis	Arecaceae	*G. resinaceum*
Eucalyptus globulus	Myrtaceae	*G. multiplicatum, G. gibbosum*
Croton macrotachyus	Euphorbiaceae	*G.* sp.

Morphological characteristics

Below are the descriptions of each species of Ganoderma based on their morphology.

Ganoderma applanatum

Basidiome annual, sessile, non-laccate, woody. Pileus 12–18 × 14.5–10 cm, sub-dimidiate, sub-applanate; brown (6E4) to greyish brown (6E3), concentrically sulcate zones with tuberculate bumps and ridges and rivulose depressions, margin soft, 2–3 mm thick, rounded, lower surface greyish yellow (4B3) to light brown (6D5). Pores whitish, light brown (6E4), 4–5 per mm. Context 3 cm thick, duplex; lower layer greyish orange (6B3), fibrous/pithy; upper layer greyish orange (6B3), woody. Basidiospores Q=1.5–1.7, ellipsoid, greyish orange (5B5) to light orange (5A5). Pileipellis (surface layer of the cap) is a hymeniderm, brown (6E4) to greyish brown (6E3), composed of apically acanthus-like branched cells. Context trimitic; generative hyphae, thin-walled, colourless, with clamp connections; skeletal hyphae brown (6E4) to greyish brown (6E3), dextrinoid, thick-walled; binding hyphae brown (6E4) to greyish brown (6E3), thick-walled, frequently branched at apex, septate, intertwined with the skeletal hyphae. This comprised the isolate labeled NJS59 (Figures 2 and 3).

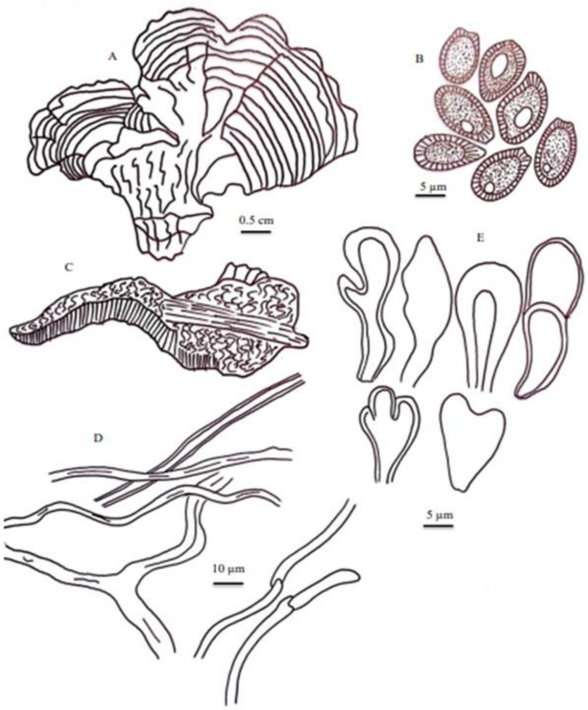

Fig 2. ***Ganoderma applanatum*** **(NJS59)** (A) Basidiome showing pilear surface (B) Basidiospores (C) Transverse section of the basidiome showing context and stratified tube layers (D) Skeletal, binding, and generative hyphae (E) Cuticle.

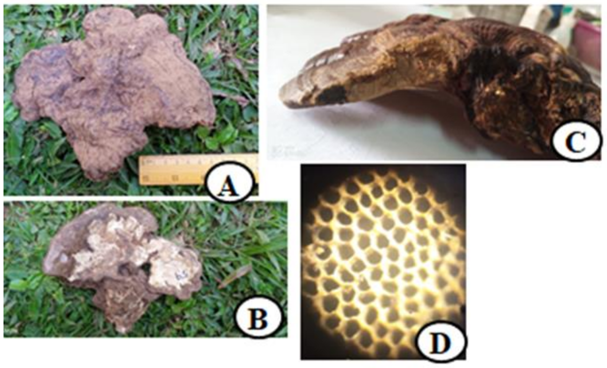

Fig 3. ***Ganoderma applanatum*** **(NJS59)** (A–B) Basidiome pilear and hymenial surfaces (C) Transverse section of the basidiome showing context and stratified tube layers (D) Close view of the hymenial surface showing pore shape.

Ganoderma australe (Fr.: Fr.) Pat.

Basidiome annual, sessile, non-laccate, woody. Pileus; 6–13 cm, sub-orbicular, plano-convex, applante, at center slightly swollen: upper surface brownish orange (6C4) to brown (6D4), distinctly concentrically sulcate, with irregularly ruptured crust overlying the pellis: margin soft, slightly lobate and concolorous with the pileus; lower surface yellowish white (4A2). Pores yellowish white (4A2), later brown (6D6), and 4–5 per mm; pores circular or sub-circular. Context up to 1.5 cm thick, dry, duplex; lower layer, brown (6D6), fibrous/pithy, composed of coarse loose fibrils; upper layer dark brown (7F8), woody, ellipsoid, brownish orange (6C8) to brown (6D8). Context trimitic. Basidiospores are mostly broadly ellipsoid at maturity, while some are distinctly tapering at the distal end. They are truncated and have a double-walled inner endosporium. Their length ranges from 4 to 11 µm, and their width is 3 to 7 µm. They are reddish-brown. Basidia were not observed. This description corresponds to the isolate labeled NJS20 (Figure 4).

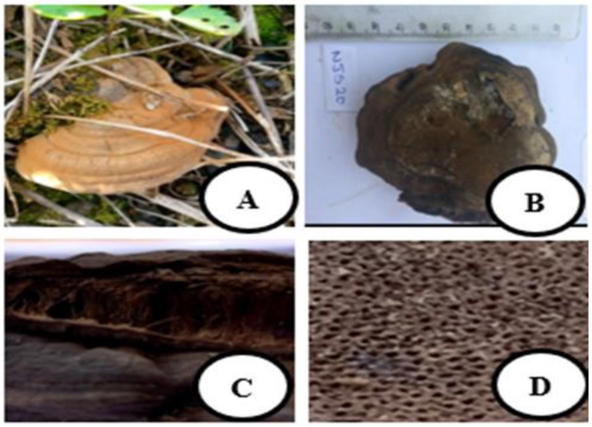

Fig 4. ***Ganoderma australe*** **(NJS20)** (A–B) Basidiome pilear and hymenial surfaces (C) Transverse section of the basidiome showing context and stratified tube layers (D) Close view of the hymenial surface showing pore shape.

***Ganoderma brownii* (Murrill) Gilb.**

Basidiomata 9.5 × 6.2 cm, perennial, sessile, dimidiate, woody. Pileus circular, generally applanate; surface glabrous, bumpy, dull, concentrically sulcate; very hard, surface light brown (6D4) to dark brown (6F4) to greyish (5B1); margin concolorous, entire, thin to thick. Context 1 – 3.5 cm thick, fibrous, homogeneous, light-brown (7D6). Pores are 5–6 per mm, angular to round and woody; pore surface is cream white; tubes are 0.4–1.5 cm thick. Hyphal system trimitic. Contextual trama: no generative hyphae were observed; skeletal hyphae 3–7 µm diameter, generally solid to thick-walled, non-septate, arboriform, yellowish brown; no binding hyphae were observed. Pileipellis is entire, solid, and golden-yellow. Basidiospores 8–13× 5–8 µm, Q = 1.63, ellipsoid, apex truncate, yellowish-brown. This comprised the isolate labeled NJS23 (Figures 5 and 6).

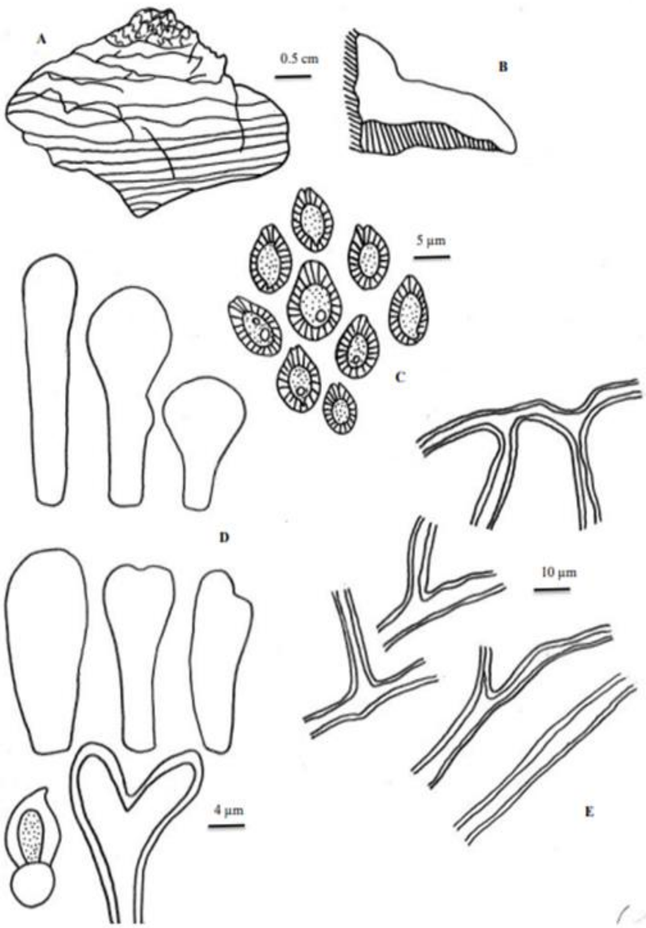

Fig 5. *Ganoderma brownii* (NJS23) (A) Basidiome showing pilear surface (B) Transverse section of basidiome showing context and stratified tube layers (C) Basidiospores (D) Cuticle (E) Skeletal and binding hyphae.

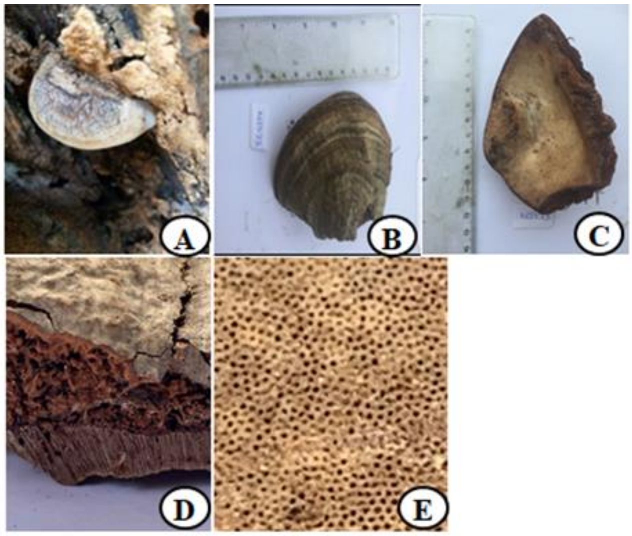

Fig 6. *Ganoderma brownii* (NJS23) (A–B) Basidiome pilear (C) Hymenial surface (D) Transverse section of the basidiome showing context and stratified tube layers (E) Close view of the hymenial surface showing pore shape.

***Ganoderma cupreum* {(Fries) Bres.}**

The basidiocarp is laccate, sessile, dimidiate, and stipitate. The stipe is laterally attached, 3 cm long and 2.5 cm wide. The pileus has reddish-brown (8E8-5) to dark brown to grey (4B2, 15B1) to golden yellow to whitish margins (3A1) and is 10 – 8 x 5 – 7 cm. The upper surface is strongly laccate, and the margin is thin and incurved with 5 – 8 concentric zones. The pore surface is whitish, with 4 – 7 pores per mm, rounded and angular. The context colour is reddish-brown (8E8-5), with a length range from 7 mm – 1 cm, tube length 4 – 5 mm, and light brown (5D3). The size of spores is 8 – 13 µm, and the width is 6 – 7 µm, with Q = 1.4 – 1.6 µm. The basidiospores are ovoid, and the cuticle cells are clavate. This includes the isolate labeled NJBM24 (Figures 7 and 8).

Ganoderma gibbosum

Basidiome annual, sessile, non-laccate, woody. Pileus 11–13 × 10–11.5 cm, spathulate, upper surface; hard, light brown (6D5) to light brown (6D6), concentric zones with tuberculate bumps and ridges and rivulose depressions; margin wavy, 2 mm thick, concolorous with the pileus; lower surface light brown (5D4). Pores circular, 4–5 per mm. Context 3 cm thick, duplex, lower layer; brown (6E8), pithy, composed of coarse loose fibrils, upper layer; dark brown (6F8), woody, trimitic; generative hyphae thin-walled, hyaline; skeletal hyphae brown (6F8), dextrinoid, thick-walled; binding hyphae brown (6F8), thick-walled, branched, intertwined the skeletal hyphae. Pileipellis is a hymeniderm, brown (6D8) to light brown

(6D6), composed of apically acanthus-like branched cells, dextrinoid. The hyphal system consisted of hyaline, thin to thick-walled hyphae with septa, composed of generative hyphae, skeletal hyphae, and tri-dimitic hyphae with clamps connections. Basidiospores (Q = 1.46 µm), ellipsoid to elongate, brown (6D8) to light brown (6D6). Their size range was 5-7 µm wide and 7-11 µm long, and they appeared reddish-brown. This group comprised the isolate labeled NJM41 (Figures 9 and 10).

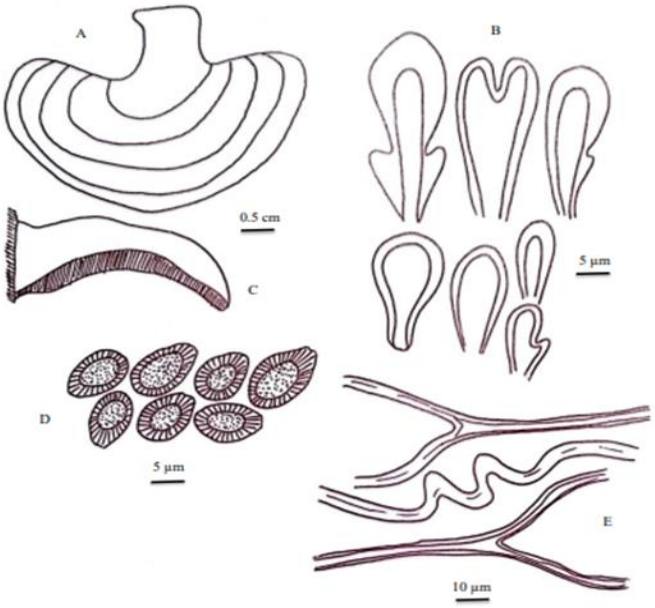

Fig 7. ***Ganoderma cupreum* (NJBM24)** (A) Basidiome showing pilear surface (B) Cuticle (C) Transverse section of basidiome showing context and stratified tube layers (D) Basidiospores (E) Skeletal hyphae.

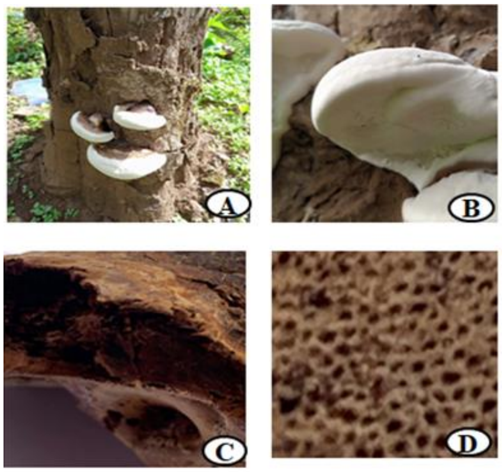

Fig 8. ***Ganoderma cupreum* (NJBM24)** (A–B) Basidiome pilear and hymenial surfaces (C) Transverse section of the Basidiome showing context and stratified tube layers (D) Close view of the hymenial surface showing pore shape.

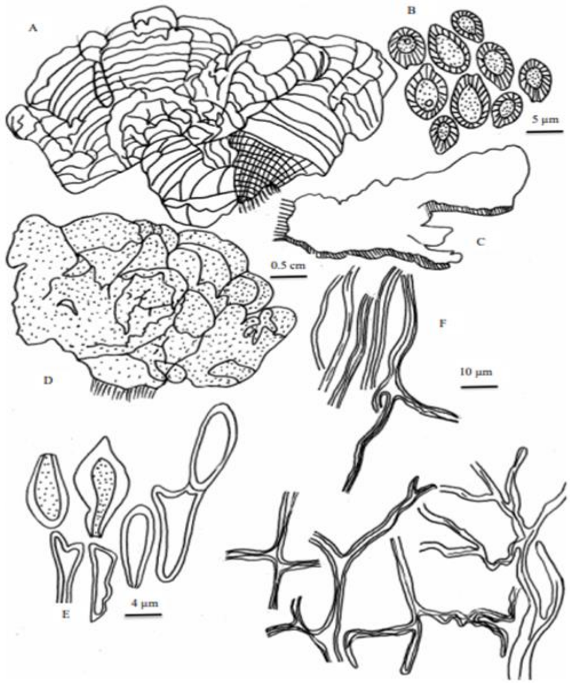

Fig 9. ***Ganoderma gibbosum* (NJM41)** (A) Basidiome showing pilear surface (B) Basidiospores (C) Transverse section of the basidiome showing context and stratified tube layers (D) hymenial surface (E) Cuticle (F) Skeletal and binding hyphae.

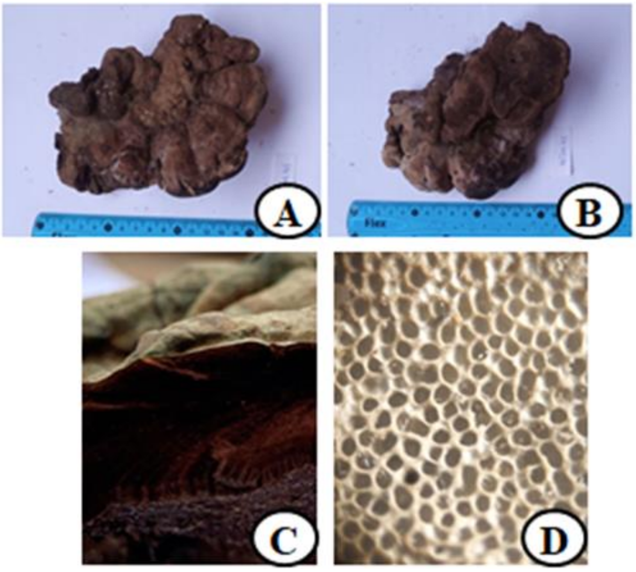

Fig 10. ***Ganoderma gibbosum* (NJM41)** (A–B) Basidiome pilear and hymenial surfaces (C) Transverse section of the basidiome shows context and stratified tube layers (D) Close view of the hymenial surface showing pore shape.

Ganoderma lucidum (Leyss: Fr.) Karst.

Basidiome annual, dimidiate, stipitate. Pileus dimidiate, flabelliform, perennial Pileus surface strongly laccate, glossy, shiny, smooth, spathulate, shallow, with clavate cuticle, thicker at the base than the margin, lightweight when dried. Pileus colour variable: light yellow to yellow, light brown (7D6), slightly brown to dark brown (6F4). Context brown to dark brown, greyish orange, primarily soft. Hymenophore di-trimitic, heterogeneous, usually yellow. Tubes are hard and woody when dried. Tube layers are single or stratified, pale to brown. Stipe lateral. Margin actively growing, entirely white when fresh, round, soft, and smooth when young, slippery when touched, and tough when broken. Pores 4–7 per mm, angular, entire, circular, regular, cream or white when young, light yellow, light orange to brown when mature. The di-trimitic hyphal system includes generative, skeletal, and binding hyphae. Basidiospores (Q = 1.5 µm), ellipsoid, double walls, truncate apex. Their size range was 6-8 µm wide and 7-13 µm long, and they appeared reddish-brown. This comprised the isolate labeled NJM01 (Figures 11 and 12).

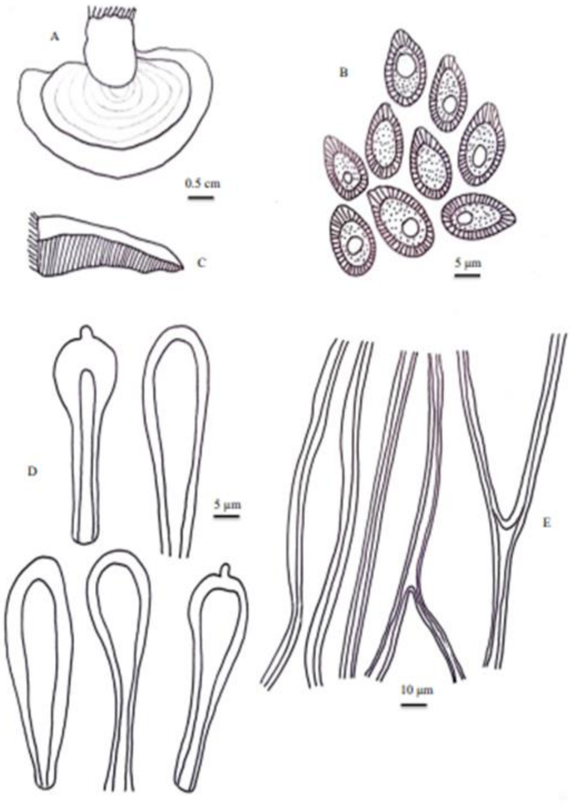

Fig 11. ***Ganoderma lucidum* (NJM01)** (A) Basidiome showing pilear surface (B) Basidiospores (C) Transverse section of basidiome showing context and stratified tube layers (D) Cuticle (E) Skeletal hyphae.

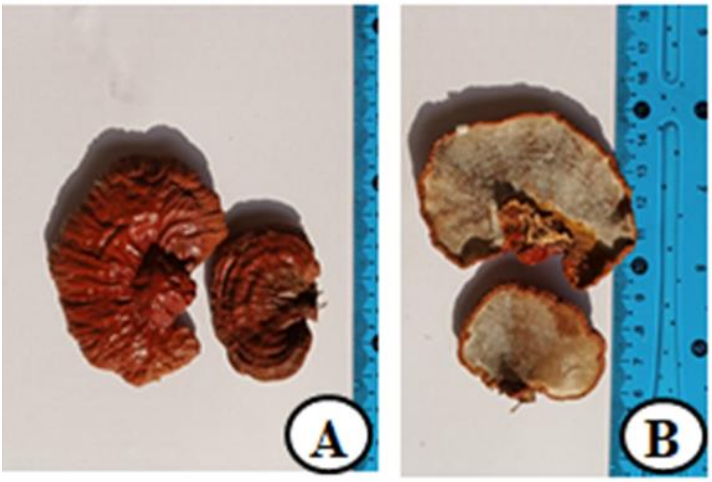

Fig 12. ***Ganoderma lucidum* (NJM01)** (A–B) Basidiome pilear and hymenial surfaces.

Ganoderma multipileum

Basidiocarp laccate, annual, stipitate, woody. Pileus 9.5-15× 6-12 cm up to 2.2 cm thick at the base, flabelliform, upper surface brownish orange, orange-rooted to reddish brown at maturity, weakly to strongly laccate, reniform, dimidiate, curly and wavy edges; lower surface yellowish white to brownish gray at maturity. The young basidiocarp's upper surface is brownish orange, orange-rooted to reddish brown, somewhat lacquered, obviously sulcate, rugged and non-rough, margin obtuse or not, white to orange-yellow. Context is 2 mm thick, and tubes are 1 cm thick. Ecocentric stipe with stipe of 1.3 x 7 cm. 6-7 rounded and angular pores. Looped margins with concentric lines. The hyphal system comprises thin-walled generative hyphae that measure 2.0-5.2 µm in diameter. The skeletal hyphae are broader, measuring 4.3-7 µm, and are yellowish-brown to reddish-brown. Binding hyphae are less in number, thick-walled, and highly branched, measuring 1.2-2.0 µm in diameter. The pileipellis is cutis with clavate and dextrinoid cells measuring 13-42 µm in length and 6.0-13.6 µm in width. Basidiospores (Q = 1.4 µm), ovoid, truncated, double walled, brownish-orange (7C4) to brown (7E5) with a hyaline outer wall (exosporium), a conspicuous echinulae, and a delicate dark brown inner wall (endosporium). The eursporium is also present. Their size range was 6-10 µm wide and 9-13 µm long, and they appeared reddish-brown. This comprised the isolate labeled NJM03 (Figures 13 and 14).

Ganoderma aff. *multiplicatum*

Basidiome annual, sessile, strongly laccate, woody. Pileus 9–16 × 5.2–11 cm, plano-convex, sub applanate; tough upper surface, several layers thick, orange (6D8) to brown (7E8), crust overlies the pellis, context fibrous, a swollen zone at the point of attachment; margin soft, 1 cm thick, rounded, white (5A1); hymenium white (5A1) to orange (5B2). Context up to 3 cm thick, duplex; lower layer brown (7E8), fibrous, soft; upper layer pale orange (5A3), woody. Pileipellis is a hymeniderm, greyish orange (5B5) to brown (6E8). Context dimitic; skeletal hyphae, light brown (6D4), thick-walled, binding hyphae light brown (6D4), thick-walled, branched, intertwined the skeletal hyphae. Generative hyphae present. Basidiospores (Q = 1.4 µm), broadly ellipsoid, greyish orange (5B5) to brown (6E8). Their size range was 5-7 µm wide and 8-12 µm long, and they appeared reddish-brown. This comprised the isolate labeled NJM05 (Figures 15 and 16).

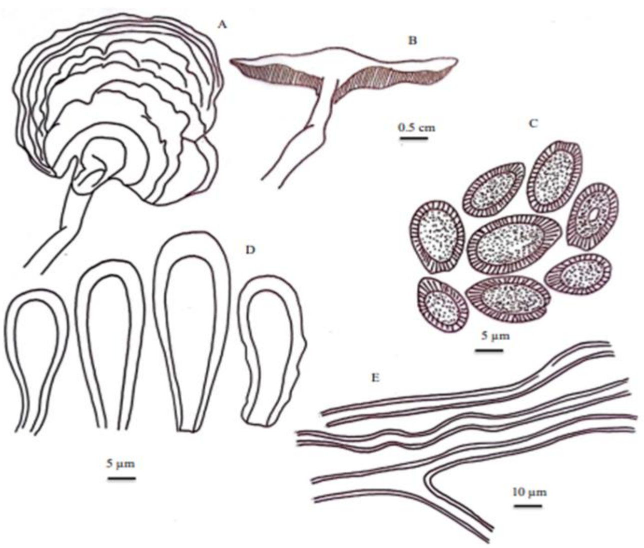

Fig 13. ***Ganoderma multipileum*** **(NJM03)** (A) Basidiome showing pilear surface (B) Transverse section of the basidiome showing context and stratified tube layers (C) Basidiospores (D) Cuticle (E) Skeletal hyphae.

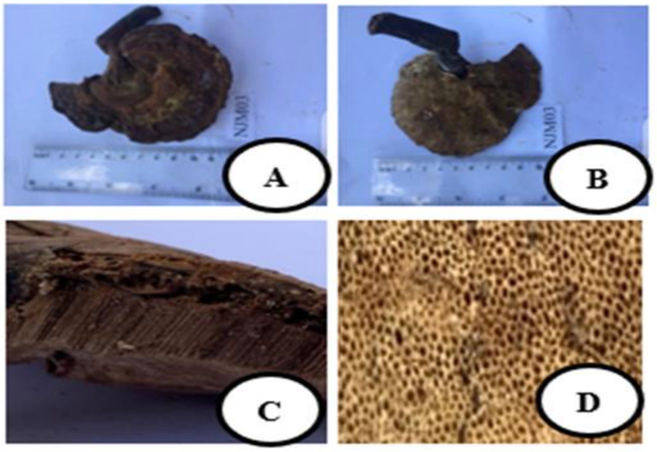

Fig 14. ***Ganoderma multipileum*** **(NJM03)** (A–B) Basidiome pilear and hymenial surfaces (C) Transverse section of the basidiome showing context and stratified tube layers (D) Close view of the hymenial surface showing pore shape.

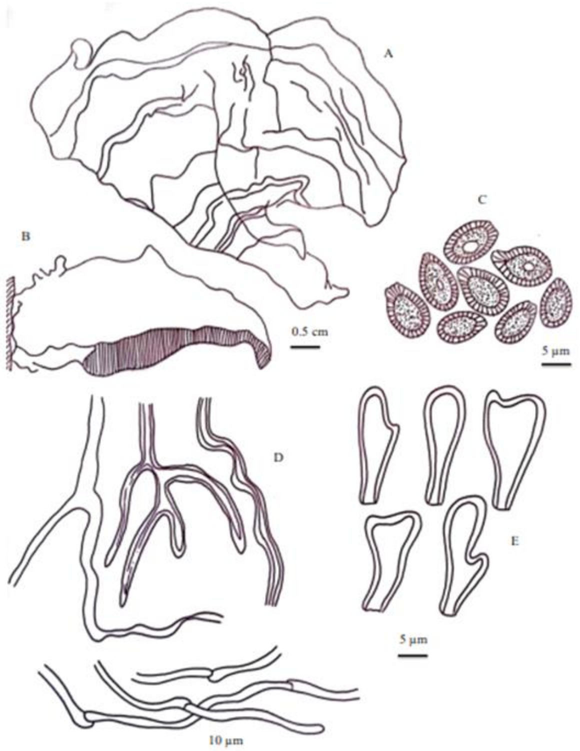

Fig 15. ***Ganoderma multiplicatum*** **(NJM05)** (A) Basidiome showing pilear surface (B) Transverse section of the basidiome showing context and stratified tube layers (C) Basidiospores (D) Cuticle Skeletal, binding, and generative hyphae.

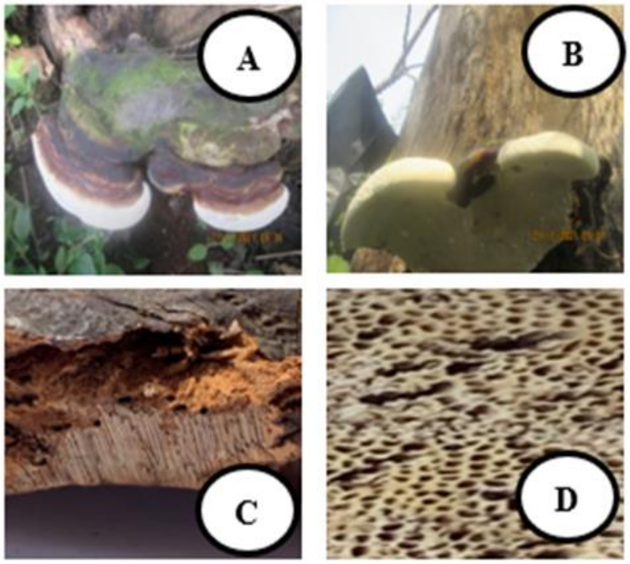

Fig 16. ***Ganoderma multiplicatum*** **(NJM05)** (A–B) Basidiome pilear and hymenial surfaces (C) Transverse section of the basidiome showing context and stratified tube layers (D) Close view of the hymenial surface showing pore shape.

Ganoderma orbiforme (Fr.) Ryvarden

Basidiome annual, sessile, non-laccate, woody. Pileus 5–16 × 3.5–7.5 cm, suborbicular, applanate, upper surface; hard, several layers thick, light brown (6D5), concentrically sulcate zones with tuberculate bumps and rivulose depressions, differentiated zone at the point of attachment, radially rugose; margin with numerous undulations and irregularities, 3 mm thick, rounded; lower surface light brown (6D4). Pores circular. Context up to 2 cm thick, dry, duplex; lower layer dark brown (7F8), pithy, composed of coarse loose fibrils, soft; upper layer light brown (5D4), woody. Basidiospores (Q = 1.6 µm), yellowish brown (5D8), elongate. Their size range was 6-8 µm wide and 10-12 µm long. Pileipellis is a hymeniderm, dark brown (7F8), composed of apical acanthus-like branched cells, dextrinoid. Context trimitic; generative hyphae thin-walled, hyaline; skeletal hyphae light brown (5D6), thick-walled; binding hyphae brown (5D6), thick-walled, branched, intertwined the skeletal hyphae. This comprised the isolate labeled NJM37 (Figures 17 and 18).

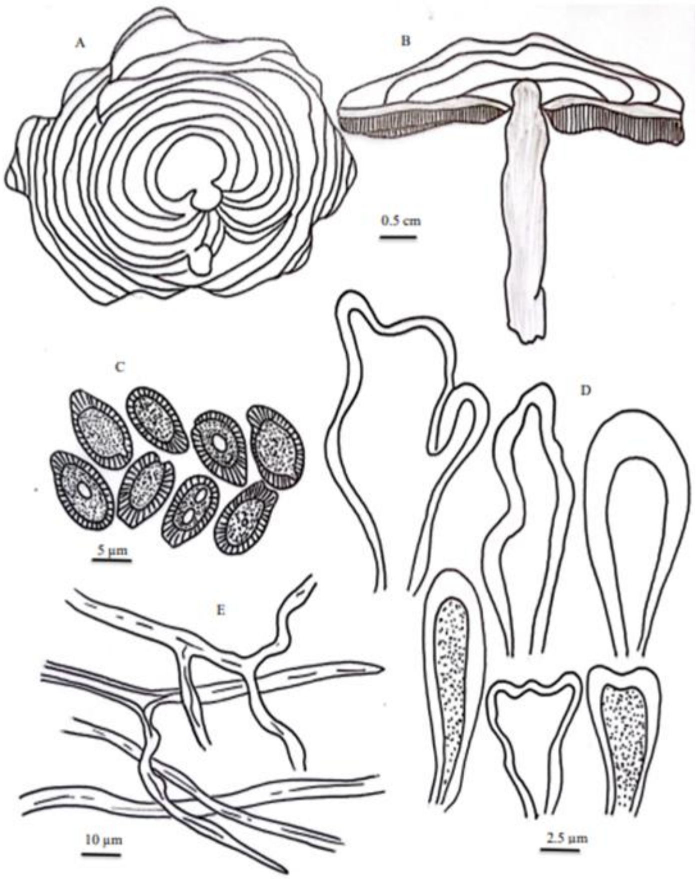

Fig 17. *Ganoderma orbiforme* (NJM37) (A) Basidiome showing pilear surface (B) Transverse section of the basidiome showing context and stratified tube layers (C) Basidiospores (D) Cuticle (E) Skeletal and binding hyphae.

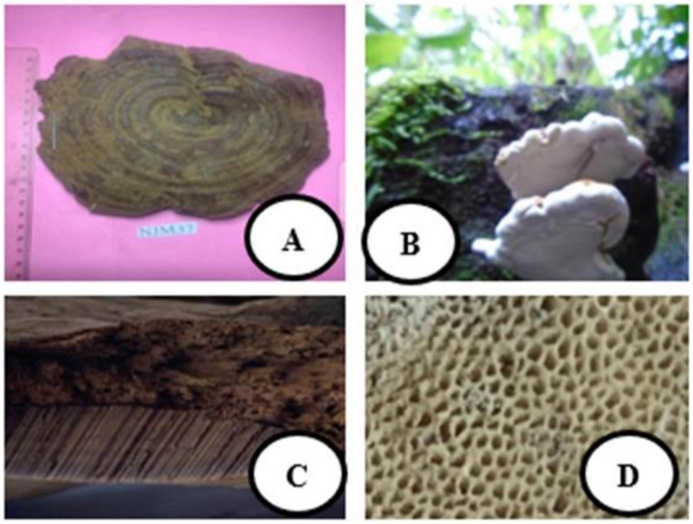

Fig 18. *Ganoderma orbiforme* (NJM37) (A–B) Basidiome pilear and hymenial surfaces (C) Transverse section of the basidiome showing context and stratified tube layers (D) Close view of the hymenial surface showing pore shape.

Ganoderma resinaceum

Basidiome perennial, sessile, laccate, corky. Pileus 7–27.5 × 4–14 cm, sub-orbicular, rotund, upper surface; reddish brown (8E8) to dark brown (8F8), concentrically sulcate zones with tuberculate bumps and ridges and rivulose depressions, radially rugose, margin; blunt to truncate, greyish orange (5B3), lower surface; light brown (7D5). Pores greyish brown (7D3), bruising brown (8E8), pores circular, 5–6 per mm. Context up to 4 mm thick, duplex, lower layer reddish brown (8E8), fibrous; upper layer reddish brown (8E8), corky to woody. Basidiospores (Q=1.4–1.6 µm) ellipsoid, light orange (5A5), brownish orange (6C8) to light brown (5A5). Their size range was 5-6 µm wide and 7-10 µm long. Pileipellis, a hymeniderm, brownish orange (6C8), clavate-like cells. Context dimitic; skeletal hyphae thick-walled, greyish brown (5B5); binding hyphae thick-walled, branched, light brown (7D5). This comprised the isolate labeled NJM15 (Figures 19 to 20).

***Ganoderma weberianum* (Bres. and Henn.)**

Basidiocarp strongly laccate, stipitate, stipe up to 4.5 x 2.5 cm, pileus colour reddish brown (8E8-5), yellowish red, 1 – 3 concentric zones. The margin is thin and incurved; the margin colour white to yellow, with some rounded. The context colour is brown and light yellow, and one resinous layer is present in the woody context of the pileus. Tube length 0.5 – 0.7 cm. The diameter of the pileus ranges from 5 – 10 cm. The pore surface is cream white, circular, pores 2 – 5 per mm. Context is 4 cm long and light brown with a few gasterospores. The hyphal system of this organism is trimitic. The generative hyphae are thin-walled, aseptate, and 2-5 µm thick. They rarely branch. The skeletal hyphae are clampless, septate, thick-walled, and branched. They are 3-5.5 µm thick. The binding hyphae are of the bovista type, clampless, aseptate, thick-walled, and much branched. They are 1-5 µm thick. The basidiospores are light yellowish and broadly ellipsoid. They measure 3.0–3.5 × 2.0–3.0 µm. This comprised the isolate labeled NJM07 (Figure 21).

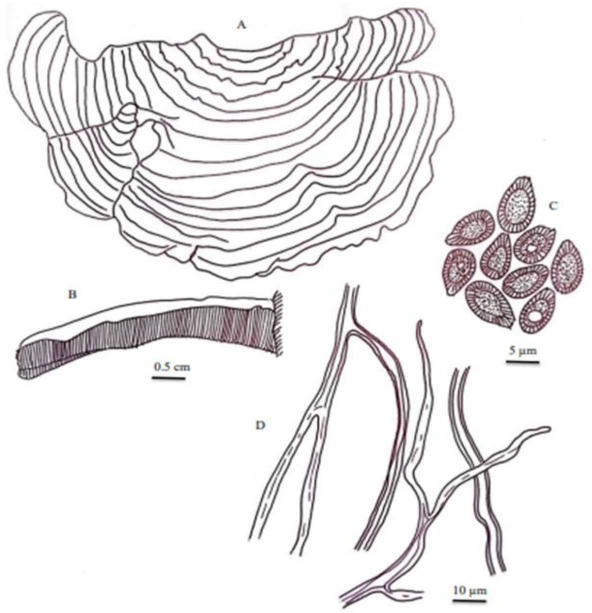

Fig 19. *Ganoderma resinaceum* (NJM15) (A) Basidiome showing pilear surface (B) Transverse section of the basidiome showing context and stratified tube layers (C) Basidiospores (D) Skeletal and binding hyphae.

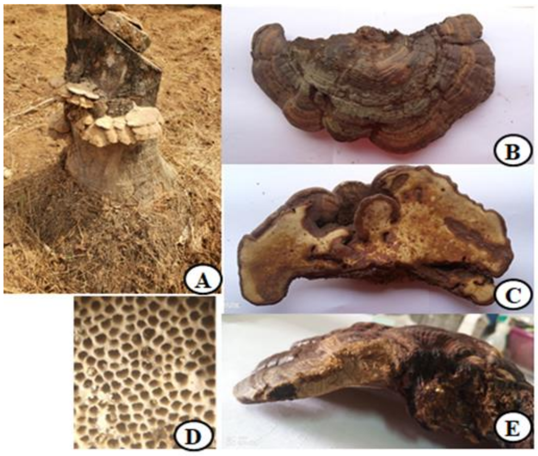

Fig 20. *Ganoderma resinaceum* (NJM15) (A–B) Basidiome pilear (C) Hymenial surface (D) Close view of the hymenial surface showing pore shape (E) Transverse section of the basidiome shows context and the stratified tube layers.

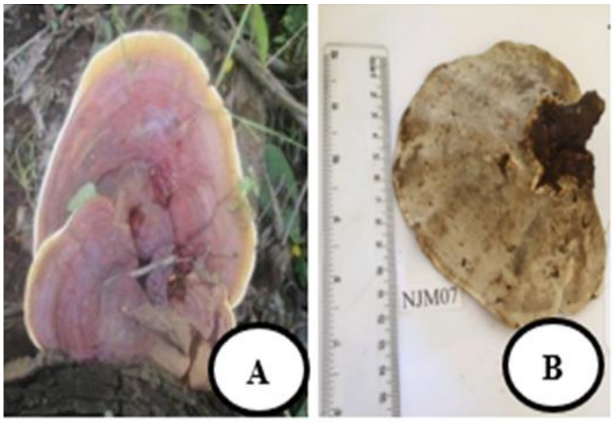

Fig 21. *Ganoderma weberianum* (NJM07) (A–B)

Discussion

The present study identified eleven species of *Ganoderma* by comparative morphology, which are *Ganoderma cupreum, G. weberianum, G. multiplicatum, G. lucidum, G. multipileum, G. australe, G. applanatum, G. resinaceum, G. orbiforme, G. brownii* and *G. gibbosum.* Previously, using the same method, Kinge (2012) and Kinge & Mih (2014) identified six species in Cameroon: *G. multiplicatum*, *G. lucidum*, *G. resinaceum*, *G. cupreum*, *G. weberianum* and *G. australe*. Comparative morphology for species identification in developing countries is due to its affordability and accessibility. Many authors, such as Turner (1981), have employed this method to examine the taxonomy of *Ganoderma* in Cameroon. For instance, Nunez & Daniels (1999) identified *G. lucidum* and *G. cf. multiplicatum* in the Dja biosphere reserve, while Douanla-Meli (2007) described *G. lucidum, G. resinaceum,* and *G. australe* in the Mbalmayo forest reserve. However, this study identified 11 species of *Ganoderma* from Mezam Division, increasing the known species in Cameroon to twenty-two.

Ganoderma is characterized by high morphological variability (Moncalvo & Ryvarden 1997; Douanla-Meli & Langer 2009). The variability in morphology could be due to environmental factors. Also, the lack of distinct morphological features makes it challenging to accurately identify and classify *Ganoderma* species. Different host plants and geographic conditions may affect the diversity of *Ganoderma* species and the morphology and pigmentation of their fruiting bodies (Smith & Sivasithamparam 2003; Kinge et al. 2015). This study identified *G. multipileum, G. applanatum, G. orbiforme, G. brownii,* and *G. gibbosum* for the first time in Cameroon because of the gap in Ganoderma diversity.

This study identified nine host trees. Some species were host-specific, while others were on multiple hosts. *G.*

weberianum had as host *Mangifera indica*, *G. australe* preyed on *Persea americana*. *G. resinaceum* was a host specific to *Elaeis gineensis*. *G. cupreum, on Ficus* sp., and *G. orbiforme* on *Cola acuminata*. *Eucalyptus globulus* (Mawar et al. 2020; Morera et al. 2021), *Ficus sp.* (Mawar et al. 2020; He et al. 2022), *Mangifera indica* (Foroutan and Jafary, 2007), Edy et al. (2022) reported *Persea americana* to be a host tree to *Ganoderma* species. *Persea americana, Albizia adianthifolia,* and *Mangifera indica* were this study's most susceptible host trees. Kinge et al. (2015) also reported that some *Ganoderma* species can infect *Persea americana* and *Elaeis guineensis*. Tchotet Tchoumi et al. (2019) reported different host ranges of *Ganoderma* species associated with *G. australe, G. cupreum,* and *G. resinaceum* in South Africa. *Ganoderma resinaceum* is related to basal stem rot disease in oil palms. This study highlights the significant impact of this genus on horticulture and forestry, including fruit trees (*Avocado, Mangoes*) and forest trees (*Albizia adianthifolia, Cola acuminata, Maesopsis eminii,* and *Ficus sp*.).

Ganoderma is a type of fungus that usually grows on dead tree stumps, depending on the preferences of its host. However, three species of Ganoderma (*G. brownii, G. gibbosum,* and *G. australe*) inhabited living trees, *Albizia adianthifolia* and *Persea americana,* which confirms that they are saprophytes and plant pathogens. This study and observations have revealed a need for more information on the diversity and distribution of *Ganoderma* in Cameroon, which conforms with the point made by Douanla-Meli & Langer (2009) about the insufficient knowledge of macrofungi in Cameroon. The diversity of *Ganoderma* may have affected their distribution across different sites and hosts. According to Kinge (2012), the spores may not have had enough time to expand into other habitats, which could explain why certain species in this study inhabited specific locations and hosts.

Additionally, some species may have a habitat-specific nature or short-lived spores, which could also contribute to their limited distribution. However, despite these factors, species of *Ganoderma* are generally well distributed. Certain species, such as *G. lucidum, G. applanatum, G. gibbosum,* and *G. orbiforme,* can remain dormant during unfavorable periods, which may explain their abundance. Symptoms of basal stem rot disease occurred in various hosts, including *Persea americana* (avocado), *Albizia adianthifolia, Mangifera indica* (mango), *Cola acuminata, Elaeis guineensis* (oil palm), *Maesopsis eminii, Ficus sp.,* and unidentified hardwoods. Numerous studies worldwide investigate basal stem rot disease affecting oil palms caused by various species of Ganoderma, such as in Malaysia (Lau et al. 2022; Mooralitharan et al. 2023), Indonesia (Rahayu et al. 2021; Edy et al. 2022), Papua New Guinea (Gorea et al. 2020; Wong et al. 2022), and Cameroon (Kinge et al. 2015; 2017). A recent survey by Edy et al. (2022) highlighted the ability of these *Ganoderma* species (*G. lucidum, G. austral* and *G. resinaceum*) to survive on different hosts, including living and dead trees. Although there may be limitations with morphological characters, it is still crucial to study *Ganoderma* species from Cameroon using morphological characters supplemented with molecular methods where possible.

Conclusion

This study observed the different morphological characters of *Ganoderma* species collected from nine villages and identified eleven morphological basidiocarps of *Ganoderma* around households and forests in the Mezam division, which includes *G. cupreum, G. weberianum, G. multiplicatum, G. lucidum, G. multipileum, G. australe, G. applanatum, G. resinaceum, G. brownii, G. orbiforme,* and *G. gibbosum* implying that the Mezam division is diverse in terms of *Ganoderma* species. It also listed nine economically significant trees to be hosts to *Ganoderma* species, which were *Persea americana, Elaeis gineensis, Mangifera indica, Maesopsis eminii, Cola acuminata, Ficus* sp., *Albizia adianthifolia, Eucalyptus globulus,* and *Croton macrostachyus*, still implying that Ganoderma can grow on diverse hosts.

Conflict of interest

The authors declare that they have no conflict of interest.

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