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Diversity and biological characteristics of macrofungi of district Bajaur, a remote area of Pakistan in the Hindu Kush range

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A R T I C L E I N F O

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A B S T R A C T

The present study was carried out to document the diversity and ecological characteristics of macrofungi of Bajaur, Pakistan. The diversity of macrofungi comprised 51 species belonging to 22 families and 37 genera. The families Agaricaceae (7 species) and Psathyrellaceae (7 species) were found dominant followed by Tricholomataceae (4 species), Fomitopsidaceae and Polyporaceae (4 species each) and Amanitaceae (3 species). White (23 species), brown (11 species), and yellow were the most prevalent morphological colours in basidiocarps (8 species). Among the identified species, 32 were saprophytic in nutrition followed by 7 parasitic, 6 saprophytic and parasitic both, while 6 mycorrhizal that make association with higher plants. The distribution of macro-fungal species in the three tehsils of Bajaur was also evaluated based on Shannon diversity index, Simpson diversity index and evenness. The highest Shannon diversity index and Simpson diversity index were found for tehsil Utman Kheil at 3.73 and 0.97, while the maximum value of evenness for tehsil Khar with 0.92 value. The results indicate a very high species richness of the study site. Four species out of the total were identified to be new reports from Pakistan. This survey's findings suggested that there is a wide variety of macrofungi that might be used as food and alternative medications if further research is carried out.

1. Introduction

Fungi are a diverse group of heterotrophic organisms composed of both unicellular and multicellular species [1]. There have been many estimations of the total number of fungi in the world. Almost 100,000 species of fungi were reported by Bisby and Ainsworth [2]. According to Hawksworth [3], there are 1.5 million different species of fungi worldwide. The total number of fungi was estimated to be between 3.5 and 5.1 million [4]. Fungi are categorized as the second largest biotic community after insects, with estimated species between 2.8 and 3.8 million [5,6]. There are currently 149,974 recognized species of macrofungi [7], among them, 41,000 species belonging to basidiomycetes and ascomycetes [8,9]. Many of these fungi are hidden among complex species and many more are still unidentified [9]. Currently, an average 2000 new species of fungi discovered per year as compared to 1000 to 2000 a decade ago [10].

Macrofungi perform a variety of important functions in ecosystems as mutualists, pathogens, decomposers, or saprotrophs [11]. Due to their vital role in the ecosystems' functioning, such as nutrient cycles and wood decomposition, they are considered ecosystem

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resources for conservation [12]. For instance, pathology, plant nutrition, abiotic and biotic stress tolerance, and soil carbon cycling are the processes of the ecosystem that are regulated by macrofungal diversity [13]. Some of them are used as foods and medicines, while others are toxic. They are cosmopolitan in distribution often quite specific in their nutritional and ecological requirements [14]. Environmental variables such as temperature, rainfall and soil characteristics of an area influence the fungal community [15]. Exploration of the diversity of macrofungi is still lacking globally and researchers are unable to count the variety of macrofungal species present in any given ecosystem due to taxonomic constraints, a lack of qualified mycologists and relatively few published comprehensive, long-term research [16,17]. Ahmad et al. [18] recorded 4500 species from Pakistan to which new genera and species were added in the last two decades. There are 338 macrofungi species reported from various parts of Pakistan and the updated list of fungi includes about 114 genera of both Ascomycetes and Basidiomycetes [17].

The reviewed literature showed that the macrofungi diversity of district Bajaur, Pakistan has not been studied previously. The area has a rich diversity of macrofungi, so there is an immense need to identify and explore its diversity. This checklist should hopefully encourage more mycological research in Pakistan.

2. Materials and methods

2.1. Study area

Bajaur is the tribal district of Khyber Pakhtunkhwa province located in the North-West of Pakistan. Geographically, it is surrounded by district Mohmand in the South-West, Kunar province of Afghanistan in the North-West, district Dir in the North-East and district Malakand in the South-East. Bajaur shares a 52 Km border with the Afghan province of Kunar. This Border of Bajaur consists of hills, valleys and passes which are caped with snow during the winter season. Latai Sar Pass, Ghakhi Pass and Nawa Pass are the famous routes of transportation and communication between the people of Bajaur and the Kunar province of Afghanistan. This region is characterized by typical Montane-Temperate vegetation. The climatic conditions remain considerably variable, with snowfall covering the mountain peaks in the winter and high temperatures in the summer, with monsoon rain falling in July and August (Fig. 1).

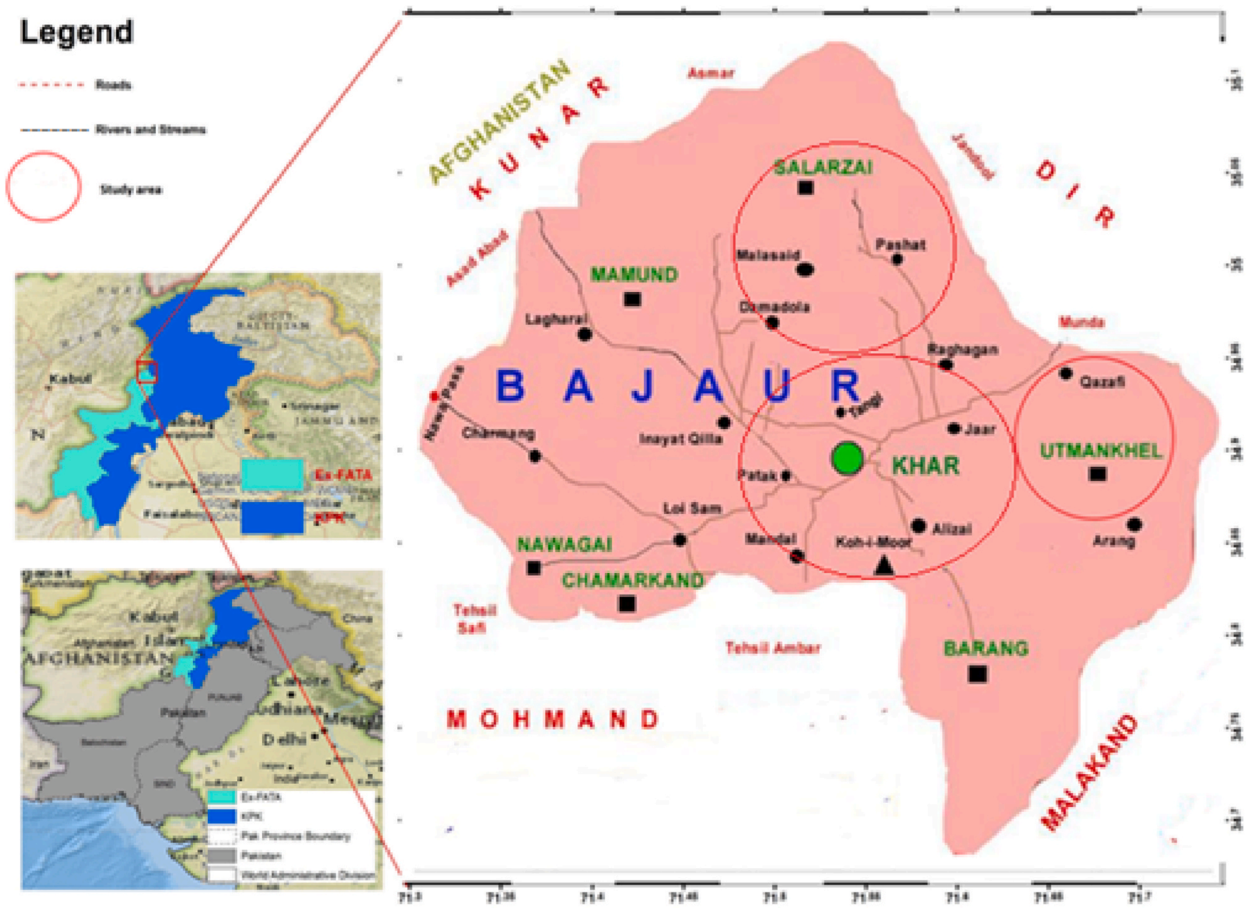

Fig. 1. Map of the research area.

Table 1
Ecological characteristics of macrofungi of District Bajaur.

Species name	Family	Voucher No.	Mode of Nutrition	Growing season	Fruiting season	Collection area	Morphology				Previous reports
							Pileus Diameter (cm)	Stipe length (cm)	Gill	Colour	
Amanita nehuta G.S. Ridl.	Amanitaceae	MFA. BOT.04	Mycorrhizal	Jun–Aug	Aug–Sep	Salarzai	6–10	12–20	+	S	Khalid (2022)
Amanita pallidorosea Zhang & Yang.	Amanitaceae	MFA. BOT.02	Mycorrhizal	Mar–Aug	Aug–Sep	Salarzai	2.5–12	4–12	+	W	Khalid (2022)
Amanita rubescens Pers.	Amanitaceae	MFA. BOT.03	Mycorrhizal	Jun–Oct	Oct–Nov	Dag Qala	6.1–10.7	10–15	+	R	Khalid (2022)
Bovista plumbea Pers.	Agaricaceae	MFA. BOT.06	Saprophytic	Jun–Nov	Nov–Dec	Bandagai	1.5–3.5	–	–	W	Khalid (2022)
Callistosporium luteo-olivaceum (Berk. & M.A. Curtis) Singer	Tricholomataceae	MFA. BOT.07	Saprophytic	Jun–Nov	Nov–Dec	Kausar Safiabad	1–4	2–5	+	Y	Khalid (2022)
Candolleomyces candolleanus (Fr.) D. Wächt. & A. Melzer	Psthyrellacaae	MFA. BOT.46	Saprophytic	Jun–Nov	Nov–Dec	Kausar	1–1.5	–	+	B	Khalid (2022)
Cantharellus cinereus Pers.	Cantharellaceae	MFA. BOT.08	Mycorrihizal	Mar–Jun	Jun–Jul	Salarzai	2–8	5–10	+	Y	Khalid (2022)
Chlorophyllum molybdites (G. Mey.) Massee.	Agaricaceae	MFA. BOT.09	Saprophytic	Jun–Nov	Nov–Dec	Bandagai	4–8	8–10	+	W	Khalid (2022)
Choiromyces meandriformis Vittad.	Tuberaceae	MFA. BOT.10	Parasitic	Jun–Nov	Nov–Dec	Khar	5–12	–	–	W	
Clitocybe brumalis (Fr.) Quel.	Tricholomataceae	MFA. BOT.11	Saprophytic	Mar–May	May–Jun	Shukarata	6–14.6	3–10	+	B	Sultana et al. (2011)
Clitocybe fragrans (With.) P. Kumm.	Tricholomataceae	MFA. BOT.12	Saprophytic	Aug–Sep	Sep–Oct	Bandagai	6–15	1.5–3	+	P	Sultana et al. (2011)
Conocybe pseudocrispa (Hauskn.) Arnolds	Bolbitiaceae	MFA. BOT.13	Saprophytic	Mar–Nov	Nov–Dec	Dag Qala	0.8–1.5	1.5–5	+	B	Bibi et al. (2019)
Coprinellus disseminatus (Pers.) J.E. Lange	Pasthyrllaceae	MFA. BOT.14	Saprophytic	Aug–Nov	Nov–Dec	Kausar	0.5–1.5	1.5–4	+	W	Khalid (2022)
Coprinellus micaceus (Bull.) Vilgalys, Hopple & Jacq. Johnson.	Psathyrellaceae	MFA. BOT.15	Saprophytic	Mar–Aug	Aug–Sep	Shukarata	1.5–3	3–10	+	B	Khalid (2022)
Coprinopsis cinerea (Schaeff.) Redhead, Vilgalys & Moncalvo	Psathyrellaceae	MFA. BOT.16	Saprophytic	Mar–Nov	Nov–Dec	Bandagai	0.5–2.2	3–6	+	W	Aman et al. (2022)
Coprinopsis picacea (Bull.) Redhead, Vilgalys & Moncalvo	Pasthyrellaceae	MFA. BOT.17	Saprophytic	Oct–Nov	Nov–Dec	Qazafi	7–10	3–12	+	B	
Coprinopsis variegata (Peck) Redhead, Vilgalys & Moncalvo	Pasthyrellaceae	MFA. BOT.18	Saprophytic	Jun–Jul	Jul–Aug	Kausar	5–7.5	4–12	+	W	Aman et al. (2022)
Coprinus comatus (Muller: Fries) S.F. Gray	Agaricaceae	MFA. BOT.19	Saprophytic	Apr–Nov	Nov–Dec	Qazafi	3–5	5–15	+	W	Khalid (2022)
Cyclocybe aegerita (V. Brig.) Vizzini.	Strophariaceae	MFA. BOT.01	Parasitic	Oct–Nov	Nov–Dec	Khar	3–10	6–12	+	W	
Cyclocybe parasitica (G. Steve.) Vizzini	Strophariaceae	MFA. BOT.20	Parasitic	Oct–Nov	Nov–Dec	Shukrata	5–10	5–11	+	C	
Desarmillaria tabescens (Scop.) R. A. Koch. Aime.	Physalacriaceae	MFA. BOT.05	Parasitic and saprophytic	Sep–Oct	Oct–Nov	Shukarata	1–4	2–8	+	Y	Sultana et al. (2011)
Flammulina velutipes (Curtis) Singer	Physalacriaceae	MFA. BOT.21	Saprophytic	Mar–Oct	Oct–Nov	Ghalishah	2.5–5	2.5–7.5	+	Y	Khalid (2022)
Fomitopsis pinicola (Sw.) P. Karst.	Fomitopsidaceae	MFA. BOT.22	Saprophytic	Sep–Oct	Oct–Nov	Bandagai	4.1–7	5–12	–	B	Aman et al., 2022

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Table 1 (*continued*)

Species name	Family	Voucher No.	Mode of Nutrition	Growing season	Fruiting season	Collection area	Morphology				Previous reports
							Pileus Diameter (cm)	Stipe length (cm)	Gill	Colour	
Ganoderma applanatum (Pers.) Pat.	Ganodermataceae	MFA. BOT.23	Parasitic and saprophytic	Mar–Nov	Nov–Dec	Ghalishah	3–30	5–10	–	B	Khalid (2022)
Hygrocybe chlorophana (Fr.) Wünsche	Hygrophoraceae	MFA. BOT.24	Mycorrhizal	Oct–Nov	Nov–Dec	Tankhata	–	1.5–2	+	Y	Khalid (2022)
Hypsizygus marmoreus (Peck) H.E. Bigelow	Lyphyllaceae	MFA. BOT.25	Parasitic and saprophytic	Aug–Sep	Sep–Oct	Kausar	5–15	1–2.5	+	W	Aman et al., 2022
Infundibulicybe gibba (Pers.) Harmaja	Tricholomataceae	MFA. BOT.26	Saprophytic	Jun–Nov	Nov–Dec	Dag Qala	3–9	1–2	+	Y	Khalid (2022)
Lactarius pubescens Fr.	Polyporaceae	MFA. BOT.44	Parasitic and saprophytic	Jun–Oct	Oct–Nov	Dag Qala	8–30	–	–	W	Khalid (2022)
Lactarius sanguifluus (Paulet) Fr.	Fomitopsidaceae	MFA. BOT.27	Parasitic and saprophytic	Jun–Nov	Nov–Dec	Bandagai	5–30	–	–	C	Ullah et al. (2022)
Laetiporus persicinus (Berk. & M.A. Curtis)	Fomitopsidaceae	MFA. BOT.28	Parasitic	Jun–Jul	Jul–Aug	Khair Abad	4–7.3	2–10	–	W	
Laetiporus sulphureus (Bull.: Fr.) Murr.	Fomitopsidaceae	MFA. BOT.29	Parasitic and saprophytic	Aug–Oct	Oct–Nov	Phatak	10–30	–	–	C	Razaq and Shehzad (2016)
Lepiota cristata (Bolton) P. Kumm.	Agaricaceae	MFA. BOT.30	Saprophytic	Jun–Jul	Jul–Aug	Khar	2–4	2–5.5	+	W	Khalid (2022)
Leucoagaricus nivalis (W.F. Chiu) Z. W. Ge & Zhu L. Yang	Agaricaceae	MFA. BOT.31	Saprophytic	Jun–Jul	Jul–Aug	Kausar	2–8	5–10	+	W	Jabeen et al. (2020)
Leucoagaricus serenus (Fr.) Bon & Boiffard	Agaricaceae	MFA. BOT.32	Saprophytic	Jul–Aug	Aug–Sep	Dag Qala	3–6	4–8	+	B	Sultana et al. (2011)
Leucocoprinus cepistipes (Sowerby) Pat.	Agaricaceae	MFA. BOT.33	Saprophytic	Jun–Jul	Jul–Aug	Dag Qala	3–9	1.5–2.5	+	W	Khalid (2022)
Leucocoprinus cretaceus (Bull.) Locq.	Psathyrellaceae	MFA. BOT.34	Saprophytic	Oct–Nov	Nov–Dec	Bandagai	1.5–2.5	2.5–4	+	W	Ishtiaq (2017)
Marasmius oreades (Bolton) Fr.	Marasmiaceae	MFA. BOT.35	Saprophytic	Jun–Nov	Nov–Dec	Bandagai	2–5	4–8	+	Y	Khalid (2022)
Morchella esculenta (L.) Pers.	Morchellaceae	MFA. BOT.36	Saprophytic	Mar–Aug	Nov–Dec	Arang	2–7	2–10	+	B	Aman et al. (2022)
Neolentinus lepideus (Fr.) Redhead & Ginns	Gloeophyllaceae	MFA. BOT.37	Saprophytic	Mar–Aug	Aug–Sep	Kausar	7–30	2.5–18	+	W	Khalid (2022)
Panaeolus papilionaceus (Bull.) Quél	Bolbitiaceae	MFA. BOT.38	Saprophytic	Mar–Nov	Nov–Dec	Banadagi	2–6	2–22	+	W	Razaq and Shehzad (2015)
Phallus rubicundus (Bosc) Fr.	Phallaceae	MFA. BOT.39	Saprophytic	Aug–Sep	Sep–Oct	Khar College	2–3.5	6–15	–	R	Khalid (2022)
Pleurotus dryinus (Pers.) P. Kumm.	Pleurotaceae	MFA. BOT.40	Saprophytic	Jun–Nov	Nov–Dec	Kausar	04–8	4–10	+	W	Khalid (2022)
Pleurotus ostreatus (Jacq.) P. Kumm.	Pleurotaceae	MFA. BOT.41	Parasitic	Mar–Aug	Aug–Sep	Tangkhata	4.1–7.3	5–20	+	W	Bibi et al. (2019)
Pluteus cervinus (Schaeff.) P. Kumm.	Pluteaceae	MFA. BOT.42	Saprophytic	Mar–Nov	Nov–Dec	Salarzai	1–1.5	1.5–2	+	B	Ishaq et al. (2021)
Pluteus salicinus (Pers.) P. Kumm.	Pluteaceae	MFA. BOT.43	Parasitic	Jun–Nov	Nov–Dec	Kausar	1.5–3	1.5–3.5	+	W	Khalid (2022)
Polyporus septosporus P.K. Buchanan & Ryvarden	Polyporaceae	MFA. BOT.45	Saprophytic	Mar–Nov	Nov–Dec	Shukarata	5.5–25	–	+	Y	Razaq and Shehzad (2016)

(*continued on next page*)

Table 1 (*continued*)

Species name	Family	Voucher No.	Mode of Nutrition	Growing season	Fruiting season	Collection area	Morphology				Previous reports
							Pileus Diameter (cm)	Stipe length (cm)	Gill	Colour	
Russula sanguinaria (Schumach.) Rauschert	Russulaceae	MFA. BOT.47	Mycorrhizal	Jun–Nov	Nov–Dec	Salarzai	3–10	2.5–8	+	R	Khalid (2022)
Schizophyllum commune Fr.	Schizophyllaceae	MFA. BOT.48	Parasitic	Jul–Aug	Aug–Sep	Gandaw	2.5–10	–	+	W	Khalid (2022)
Trametes versicolor (L.) Lloyd	Polyporaceae	MFA. BOT.49	Saprophytic	Nov–Dec	Dec	Gandaw	5–30	–	–	C	Khalid (2022)
Tyromyces chioneus (Fr.) P. Karst.	Polyporaceae	MFA. BOT.50	Saprophytic	Jun–Nov	Nov–Dec	Khairabad	1.5–15	–	–	W	Khalid (2022)
Xylaria polymorpha (Pers.) Grev.	Xylariaceae	MFA. BOT.51	Saprophytic	Jun–Nov	Nov–Dec	Dag Qala	1–1.5	1–2.5	–	B	Khalid (2022)

2.2. Survey of the area, collection, preservation and processing of macrofungi

Regular field trips were carried out in different places in the area on a weekly basis. The fruiting body with stipe was picked up from the substratum on which it was growing with the help of a scrapper or knife or forceps and then preserved in a solution of alcohol (15 ml), formalin (25 ml) and distilled water (100 ml) following Ainsworth [19]. Samples were photographed in their natural habitats for their appropriate identification by using a digital camera. The place and date of collection, habit and habitat of each species were noted in the field diary at the time of collection [14].

2.3. Identification of macrofungi

Specimens were identified by using the relevant literature [20–24] and then confirmed with mycokeys (www.mushroomexpert.com and www.mycokeys.com). The current name of each specimen were checked and corrected with the https://www.indexfungorum.org/Names/Names.asp.

2.4. Species diversity

The Shannon diversity index, Simpson diversity index and evenness were analyzed through PAST Software.

2.5. Indigenous uses

The indigenous knowledge regarding edibility and toxicity of macrofungi species were collected from the villagers and local inhabitants through interviews during the survey and verified with available literature.

3. Results

3.1. Diversity of macrofungi

Macrofungi were gathered from three tehsils i. e, Khar, Utman Kheil and Salarzai in the district of Bajaur in 2022 (April to October) to assess their diversity and ethnomycology. A total of 51 species of macrofungi belonging to 22 families and 37 genera were collected and identified. Family Agaricaceae and Psathyrellaceae were found dominant with 7 species followed by Tricholomataceae with (4 species), Fomitopsidaceae and Polyporaceaewith (4 species each), Amanitaceae (3 species), Bolbitiaceae, Physalacraceae, Pluteaceae and Strophariaceae with two species each, whereas the Strophariaceae, Cantharellaceae, Ganodermataceae, Gloeophyllaceae, Hygrophoraceae, Lyphyllaceae, Marasmiaceae, Morchellaceae, Phallaceae, Russulaceae, Tuberaceae, Xylariaceae had only one species each (Table 1, Fig. 2). The documented species were compared with the previously reported species from Pakistan [17,25–31]. In the present finding 28 speies were found similar with the study of Khalid [17], 4 species with Sultana et al. [25], 5 species Aman et al. [30], 3 with Razaq and Shehzad [26,27], 2 with Bibi and Rehman [28] and a single species with Jabeen et al. [29] and Ullah et al. [31] each. Out of 51 species, 5 were reported as new species for the first time from Pakistan which are *Cyclocybe aegerita, Choiromyces meandriformi, Coprinopsis picacea, Cyclocybe parasitica and Laetiporus persicinus* (Table 1).

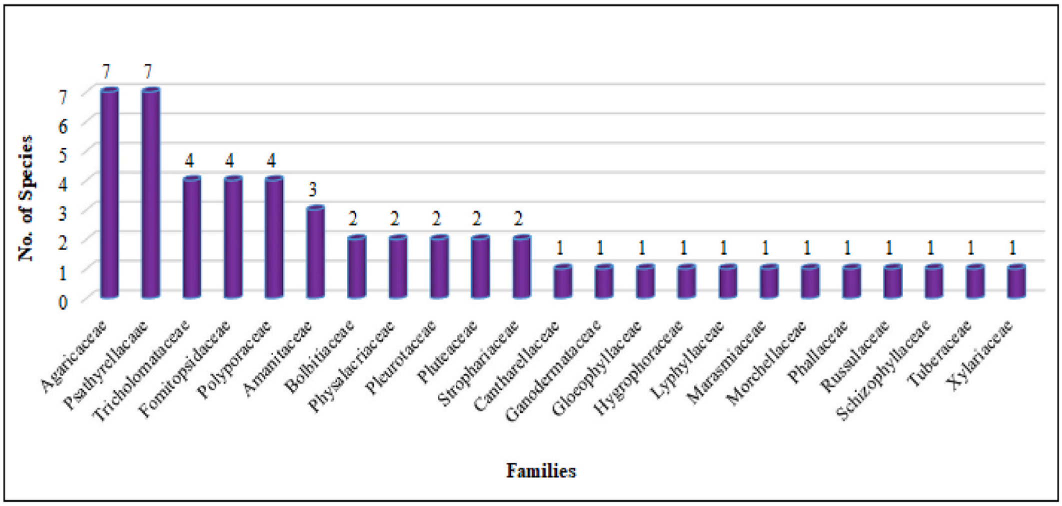

Fig. 2. Diversity and family wise distribution of species.

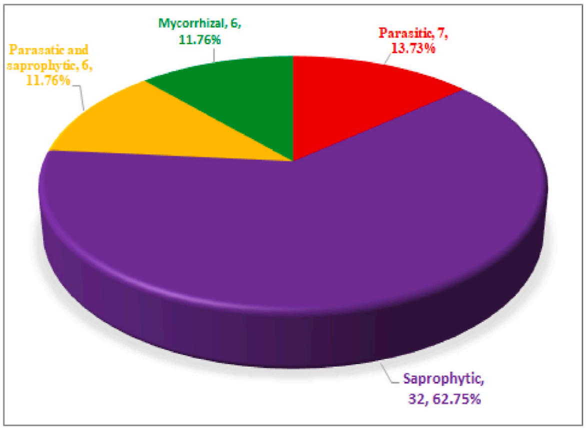

Fig. 3. Nutritional pattern of the species.

3.2. Mode of nutrition

According to the ecological preferences, in the current investigation, the majority of macrofungi were saprophytic (32 species), followed by parasitic (7 species), saprophytic and parasitic, and mycorrhizal species (6 species each) as shown in Fig. 3.

3.3. Morphology of basidiocarp

The morphology of the basidiocarp of fungi shows variation from species to species in a particular habitat. The basidiocarp colour morphology of the species was comprised of white (23 species), brown (11 species), yellow (8 species), cream (4 species), red (3 species), silver and pink (1 species each) as shown in Fig. 4. The shape of the pileus, their diameter, thickness and length of stape showed great variation from species to species. The largest sizes of basidiocarps were observed for *Laetiporus sulphureus, Polyporus pubescens, Neolentinus ponderosus, Trametes versicolor* and *Laetiporus cincinnatus* as shown in Table 1.

3.4. Diversity indices of the species among the three tehsils

According to the Shannon diversity index, Simpson diversity index, and evenness, the distribution of macrofungal species in the three tehsils of Bajaur was also assessed. The tehsil Utman Kheil has the highest value of Shannon diversity index of 3.73 followed by the tehsil Salarzai of 3.49, and the tehsil Khar of 3.06. Similar to this, tehsils Khar and Utman Kheil showed more Simpson variety with values of 0.97 and 0.96 respectively, while tehsil Khar had the highest value of evenness at 0.92. The findings shows that the research location has a very high species richness (Table 2).

3.5. Utilization and toxicity of macrofungi

The survey related to the edibility status of macrofungi was also undertaken and the result revealed that out of 51 macrofungal species collected 23 macrofungal species were found to be edible, 18 were non-edible, 5 were unknown while 5 choices (Fig. 5). Some species of mushrooms such as *Agrocybe aegerita*, *Amanita nehuta*, *Bovista plumbea* and *Coprinellus micaceus* are extremely delicious and having both nutritional and therapeutic benefits.

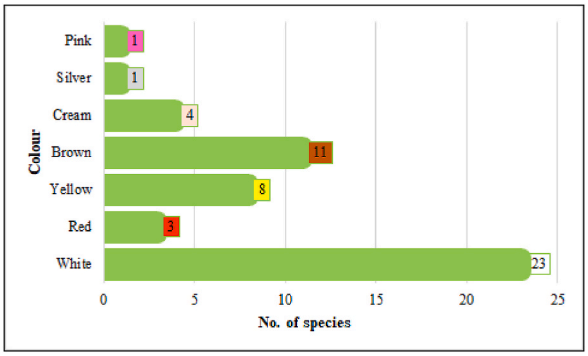

Fig. 4. Colour morphology of the species

Table 2
Shannon diversity index, Simpson diversity index and evenness of macrofungi of District Bajaur.

	Khar	Utman Kheil	Salarzai
No. of species (s)	23	49	36
Total no. of individuals (N)	75	105	220
Shannon diversity index (H)	3.06	3.73	3.49
Simpson diversity index (1-D)	0.95	0.97	0.96
Evenness (E)	0.92	0.85	0.91

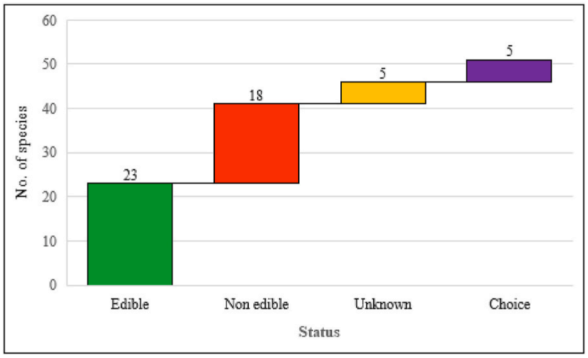

Fig. 5. Utilization status of the macrofungi.

4. Discussion

A wide variety of naturally growing macrofungi can be found in Bajaur due to its favorable environmental conditions. Macrofungi diversity varies significantly as a result of the prevailing environmental conditions such as decaying wood logs, damp soil, sandy soil, humus and leaf litter [14]. The variations in the distribution of macrofungi can also be attributed to many factors, including rainfall, the amount of suitable substrate, damp woods with constantly high air humidity, and forest type [32]. The results of this study indicate that more species bloom during the rainy season from July to September while complete absence in the winter in December and January. Mushrooms are seasonal fungi that occupy a diverse habitat in an ecosystem [33]. Geographically, Pakistan is situated in a subtropical region with four distinct seasons and a unique climatic environment. The months of July and August have plenty rainfall, and high temperatures that favour the growth of fungi.

Their abundance on the substrate is related to the organic matter and thus containing nitrogen content of soil [34]. For some species like *Morchella esculenta*, the preferred soil is alkaline containing limestone but also in acidic. The saprophytic species grow on stumps or logs of deciduous trees or attached to burred wood, deriving their nutrients from dead and decomposing organic matter [35]. The mycorrhizal species can grow alone, scattered, or in groups, and they often form associations with conifers. Some species are found in disturbed areas including roadsides, openings, rivulets, gullies, timber clearings, and hillsides left over after forest fires. The parasitic species widely distributed that grow on a variety of tree species including *Pinus roxburgii, Qurcus incana, Morus alba, Morus nigra, Aliantus altissimia, Melia azadarch, Populus nigra and Ficus palmata.*

The morphology of the basidiocarp of fungi is always different due to the environmental conditions of a particular habitat [36]. The colour of the pileus surface shows variations from red to yellow and white. Sometimes change into deep brown with age or upon drying. These colourations of basidiocarps help in the identification of species. Variations between species can be seen in the size of the basidiocarp, the diameter of the pileus, and the length of the stapes (Table 1). The morphology of the gills was also observed to vary in terms of texture and number. Usually, the polypores fungi are highly polyphyletic groups characterized by producing annual or perennial basidiocarps [37]. The bracket-shaped polypores on a tree's trunk or branch can either be alive or, more frequently dead. It may have a shiny upper surface or a nonlaccate fruiting body with an upper surface that seems to be dull. From species to species, basidiocarp morphologic characteristics show variation [38]. Basidiocarps vary in appearance, colour, and shape due to environmental exposures and the organic content of the substrate on which they grow and develop.

The results of this research indicate that more species bloom from July to September that is the rainy season while completely disappearing from the landscape in December and January due to harsh and cold climatic condition. The variations in the distribution of macrofungi can also be attributed to many factors, including rainfall, the amount of suitable substrate, damp woods with constantly high air humidity, and forest type. The weather condition of habitats greatly affects fungal abundance while no significant effect on soil properties was observed [39]. Geographically, Pakistan is situated in a subtropical region with four distinct seasons: spring, summer, autumn, and winter, each with its specific climatic conditions [40]. Bajaur, which lies in the northwest of Pakistan along the Pak-Afghan border, experiences a dry and temperate climate with considerable monsoon rain from July to August. For normal fungal growth generally requires warm, moist conditions, which are offered in the research region during the summer. The warm temperatures and frequent rainfall in July and August promote the growth of fungi [41]. Some species of macrofungi grow in the mixed

Fig. 6. Pectoral view of some of the macrofungi of Bajaur.

coniferous and deciduous forests in temperate and tropical regions during summer and winter. *Morchella esculenta* is an important medicinal species of mushroom that collected by the local communities and dried and sold to the local market. The other species may be economically important but the locals of the area are unaware of their nutritional and medicinal values. These macrofungi are used both economically and domestically, which may be characterized by their delectable flavour, a regular occurrence, and the ease with which the locals can identify them as safe to consume. It has a high content of protein, fiber, calcium, phosphorus, potassium, vitamins and low content of fat. The high nutritional value and bioactive content of macrofungi have piqued the interest of people who are interested in utilizing them as medicine [14,42,43].

The Shannon diversity and Simpson's diversity indices were observed as highest for tehsil Utman Kheil and Salarzai while the maximum value of evenness for tehsil Khar. These results indicate a very high species richness of the study site. Macrofungi have an extensive range of distribution patterns; some are confined only to particular ecosystems, while others are found across the globe [44]. Complete knowledge of the fungi in any locality would require continuous observation and collection over many years [45]. As a result of the fact that environmental and edaphic factors always affect the species diversity in an area. The value of 1-D ranges between 0 and 1. The greater the value of 1-D greater the diversity. Some species were discovered to be widespread among the three tehsils, which may be a consequence of comparable environmental factors. The highest number of species in Utmankheil tehsil was contributed to the frequent collections made during the study period compared to other study sites in the present study. The diversity of macrofungi varies greatly and is influenced by a variety of factors, including climate, soil type, vegetation, and agricultural techniques. the variety of macrofungi is connected with the habitat [32]. The diversity of macrofungi in a forest environment exhibits a strong relationship with a variety of tree species [46].

Although some species of macrofungi have great potential to be utilized as food and medicine due to the presence of pharmacologically active compounds and essential nutrients. The knowledge of a food's edibility is typically transmitted from generation to generation or through direct observation of insects and other animals eating mushrooms in the wild. In order to determine whether the species of mushroom is edible, the basidiocarp was rubbed on skin. By turning a metal spoon black during cooking, it was evident that the species was not edible [47]. Macrofungi contain a high nutritive value. It contains low fat, rich in fiber, protein, minerals (Ca, P, K) and vitamins. It has high nutraceutical value which has created an interest in local people in its use [42]. However, the majority of species are poisonous and contain powerful toxins that may be harmful to health even ingest in small amounts. Due to the presence of poisonous compounds including amatoxin, psilocybin, muscarine, coprine, allenic norleucine and gyromitrin in the mushrooms, both humans and animals may experience harmful side effects after consumption [48]. Accidental mushroom poisoning can have adverse health consequences or, in extreme situations, be lethal. The majority of these accidents are caused by incorrect species identification, which is frequently done using empirical and traditional knowledge. Some of the documented mushrooms in the present study cause severe effects on human health if consumed as food, such as Chlorophyllum *molybdites* ingestion can cause acute gastroenteritis with symptoms like nausea, vomiting, stomach pain, and sometimes diarrhea [49]. *Coprinus* species contain coprine toxin which blocks the active site of aldehyde dehydrogenase, leading to headache, nausea, vomiting, flushing, tachycardia, and in rare cases, hypotension [50]. Muscarine-containing species like *Clitocybe* produce cholinergic toxicity and cause bradycardia, diaphoresis, salivation, lacrimation, bronchospasm, and abdominal cramps [51]. Amatoxin is found in species of Lepiota, and Amanita that damages the liver. They disrupt RNA polymerase II, which depletes cells' protein stores. Liver failure is frequently caused by hepatic injury. Death might occur within a week in dire circumstances [52]. The consumption of *Amanita* species as food can cause nephrotoxicity that leads to renal failure and gastroenteritis [53]. Ingestion of poisonous mushrooms results in death incidents that happen every year all over the world, and many of these cases have been documented.

5. Conclusions

The current study is the first to document and record the diversity of macrofungi in the district of Bajaur, Pakistan. The current study recorded a total of 51 macrofungi species belonging to 22 families. The macrofungi showed more diversity in size, habit, habitat and morphology. This study reports five new species from Pakistan: *Cyclocybe aegerita, Choiromyces meandriformi, Coprinopsis picacea Cyclocybe parasitica* and *Laetiporus persicinus*. The restricted usage of macrofungi was due to the lack of knowledge regarding edible mushrooms. This study attempted to record and explore the macrofungi and their ecological characteristics, however, more research is required to document the active constituents that may be used as food and medicine in the future. This work will be helpful to the local population as well as other mycological and ethnomycological researchers in the region for further multidimensional study on macrofungi.

Author contribution statement

M. Zeb, A. Ullah, F. Ullah: Performed experiment; Contributed reagent, Analyzed tools or data and Wrote the paper.
A. Haq: Conceived and designed the experiment; Contributed reagent, materials, analyzed tools or data and Wrote the paper.
L. Badshah, I. Ullah, M. A. Haq: Contributed reagent, materials, Analyzed and interpreted the data and Wrote the paper.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e17818.

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