Ethnobotany of wild mushrooms in the Maamora Forest region, Northwestern Morocco

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Research

Abstract

Background: Wild mushrooms are a very important source of food, medicines as well as other biologically active compounds, and are studied intensively worldwide. The Maamora Forest is an area where the traditional use of mushrooms is still preserved, offering a unique opportunity to explore these cultural practices. The present research aims to document the rich and poorly known traditional uses of wild mushrooms from this area.

Methods: Our ethnomycological survey was carried out using a semi-structured questionnaire with 236 participants. The data were analyzed using statistical methods, including the Chi-square (χ^2) test, Multiple Correspondence Analysis (MCA), and Non-Metric Multidimensional Scaling (nMDS). Ethnobotanical indices such as Cultural Importance Index (CI), Fidelity Level (FL), and Informant Consensus Factor (ICF) were also employed.

Results: CI focuses primarily on income rather than food and ethnomedicine. Six wild edible mushrooms are used, mostly in their fresh form, as a substitute for meat and incorporated into various traditional Moroccan dishes. This study identified six wild medicinal mushrooms with varying FL and seven use categories, including anti-cancer, all with high ICF values. Two cases of mushroom poisoning in the study area were recorded. MCA showed the relationships among all tested variables, while nMDS highlighted the correlations between the distribution of wild mushrooms and their respective cantons.

Conclusions: Our ethnomycological survey brought to light methods of conservation, preparation, and application of wild mushrooms that had never been recorded in previous research. contributing to the preservation of local knowledge and supporting future studies in nutrition, pharmacology, and biodiversity conservation.

Keywords: Ethnomycology, Wild Edible Mushrooms, Medicinal Mushrooms, Poisoning Mushrooms, Maamora Forest

Background

Study of human interactions with mushrooms, including traditional knowledge and utilization, falls under ethnomycology, a relatively newer branch of ethnobiology (Boa 2004). Paleontologically, wild mushrooms existed on the earth since the Lower Cretaceous period, while their consumption by the Neanderthals was recorded around 50,000 to 60,000 years ago (Weyrich *et al*. 2017). According to Boa (2004), wild edible mushrooms (WEMs) are classified as non-timber forest products (NTFPs). Wild mushrooms (WMs) are essential to ecosystem functioning, playing a fundamental role in soil formation, nutrient cycling, carbon stocking, and mycoremediation, while also being an essential food for wildlife (Niego *et al*. 2023). Furthermore, their use is discussed in the context of ritual applications as hallucinogenic (Adams & Gallahue 2024), recreational, ornamental (Ríos-García *et al*. 2023) and of their role in myths and beliefs (Gamboa-Trujillo *et al*. 2019). WMs are also used in food industry and in cosmetics (Zhou *et al*. 2024). WEMs are widely considered as sources of income and as food for rural populations (Boa 2004, Zhu *et al*. 2019). In general, they contain high levels of carbohydrates and proteins, are low in fat and calories, and provide vitamins, minerals, dietary fibers, and bioactive compounds (Zhou *et al*. 2024). They offer a multitude of traditional medicine for many illnesses, like goiter, eczema, asthma, diabetes, skin infections, rheumatism, etc (Gafforov *et al*. 2023). Some of them are anticancer, antioxidant, immunostimulatory, anti-inflammatory, anti-neuroinflammatory, hypoglycemic, hypolipidemic, antiviral, antibacterial, and antifungal (Erbiai *et al.* 2023, Prakofjewa *et al*. 2024, Zhou *et al*. 2024).

Globally, out of the 14,000 identified macro-mycete species, 2,189 are edible and used in 99 countries (Li *et al*. 2021). Morocco, due to its biogeographical position, offers rich ecological diversity, with around 3,500 macrofungi, of which 107 species are edible, according to the inventory conducted by Ajana *et al*. (2015). In the Maamora forest alone, there are 708 macrofungi classified in 48 orders, 119 families, and 244 genera (Ouabbou *et al*. 2012).

Recently, numerous ethnomycological studies have been carried out worldwide, e.g. in Argentina (Molares *et al*. 2020), China (Wang *et al*. 2022), Croatia (Ninčević Runjić *et al*. 2024), Ethiopia (Zeleke *et al*. 2020), Indonesia (Yusran *et al*. 2024), Mexico (López-García *et al*. 2024), Pakistan (Hussain *et al*. 2023), Serbia (Zivkovic *et al*. 2021), Soviet Union (Prakofjewa *et al*. 2024) and Uzbekistan (Gafforov *et al*. 2023). According to current information, no ethnomycological study has been carried out in the Maamora forest, regardless of its rich diversity of WEMs (Abourouh 2011, El-Assfouri 2006) This scarcity of informations, combined with significant regression of this forest (Moukrim *et al*. 2022) and, consequently, reduction in mushroom habitats, makes local mycological knowledge vulnerable.

According to Benabou *et al*. (2022b), Maamora forest plays an important role in local and regional development, constituting the main source of income for local population. Furthermore, its communities have been gathering mushrooms for French people for a long time (Bertault 1979). Mushroom pickers sell their harvest at the weekly markets and roadside stands (Abourouh 2020).

Our quantitative ethnomycological study, the first in its kind, aims to help preserve and maintain traditional knowledge about wild mushrooms within Maamora Forest communities by employing ethnobiological indices and questionnaires (Hoffman & Gallaher 2007). Its main objective is to document and preserve traditional knowledge of communities located in the forest and its surroundings regarding culinary preparations, preservation methods, preparation of remedies, and uses, as well as investigate poisoning cases. Our surveys will serve as a primary database for future research in various relating fields, including nutrition, pharmacology, mycomedicine, myconanotechnology, cosmetics, toxicology, domestication, and conservation. They, certainly, will also contribute to protect and preserve this vital component of Maamora ecosystems. We hope they, additionally, will encourage emergence of more such research in various regions of the country.

Material and methods

Study area

Maamora forest is situated in the northwestern part of Morocco. It is located between 6° and 6° 45′ West and 34° and 34° 20′ North and it represents the largest cork oak area in the world, covering approximately 133,000 ha, including more than 60,000 ha of *Quercus suber* L. (Laaribya *et al*. 2021). The forest is rich in edible and poisonous mushrooms (Abourouh 2011, El-Assfouri 2006).

Maamora forest comprises 5 cantons named, from west to east, as A, B, C, D and E. It exhibits considerable fluctuations in temperature and precipitation, with annual rainfall recorded between 350 and 650 mm/year, decreasing from west to east. Mean monthly temperature ranges between 12 and 25 °C, with averages of 3.5 °C in the coldest month of January and 37 °C in the hottest ones of July or August (Cherki & Gmira 2013). Nevertheless, the last 4 years, from 2019 to 2022, have been the driest since at least the 1960s, with a rainfall deficit of 32 % (State of the Climate 2022). In general, Maamora bioclimate is sub-humid, with warm winters in the west and semi-arid, with temperate winters in the east (Benabou *et al*. 2022b). Soils characterizing the forest are generally sandy, ranging in thickness from 30 cm to 7 m (Cherki & Gmira 2013). Regrettably, an analysis of spatiotemporal dynamics reveals that 26.7 % of its total area has been significantly degraded (Moukrim *et al*. 2022). This degradation is caused by worsening climatic conditions and increasing anthropogenic pressures, including overgrazing, acorn harvesting, recreational use, peri-urban development, etc. (Benabou *et al*. 2022a).

Ethnomycological survey

The study was done between November 2022 and early May 2024 by carrying out an ethnomycological survey with people who know and use wild mushrooms. Semi-structured questionnaires (Alexiades 1996) were conducted in the Arabic language and administered to 236 informants. They are WEM pickers, merchants and users. Figure 1 shows repartition of investigation sites within the different cantons of the forest. Additionally, visits were conducted to pharmacists and Moroccan Poison Control and Pharmacovigilance Center to investigate reported cases of mushroom poisoning. Interviews took place in villagers' homes, in the forest at mushroom picking sites, and along forest roads.

Questionnaire used in this study contains two sections. The first one focused on collecting demographic data about respondents, including age, sex, family situation, education level, professional activity, monthly income, locality, and distance from the interviewee's house to the harvest sites. Second part contained information on traditional knowledge on wild mushrooms, involving parts used, harvest developmental stage (young/mature), categories of use (food, therapeutic, veterinary, hallucinogenic, beliefs and myths), income, preparation methods, culinary local recipes, preservation techniques, preparation of remedies, and identified complications or fatalities after consumption.

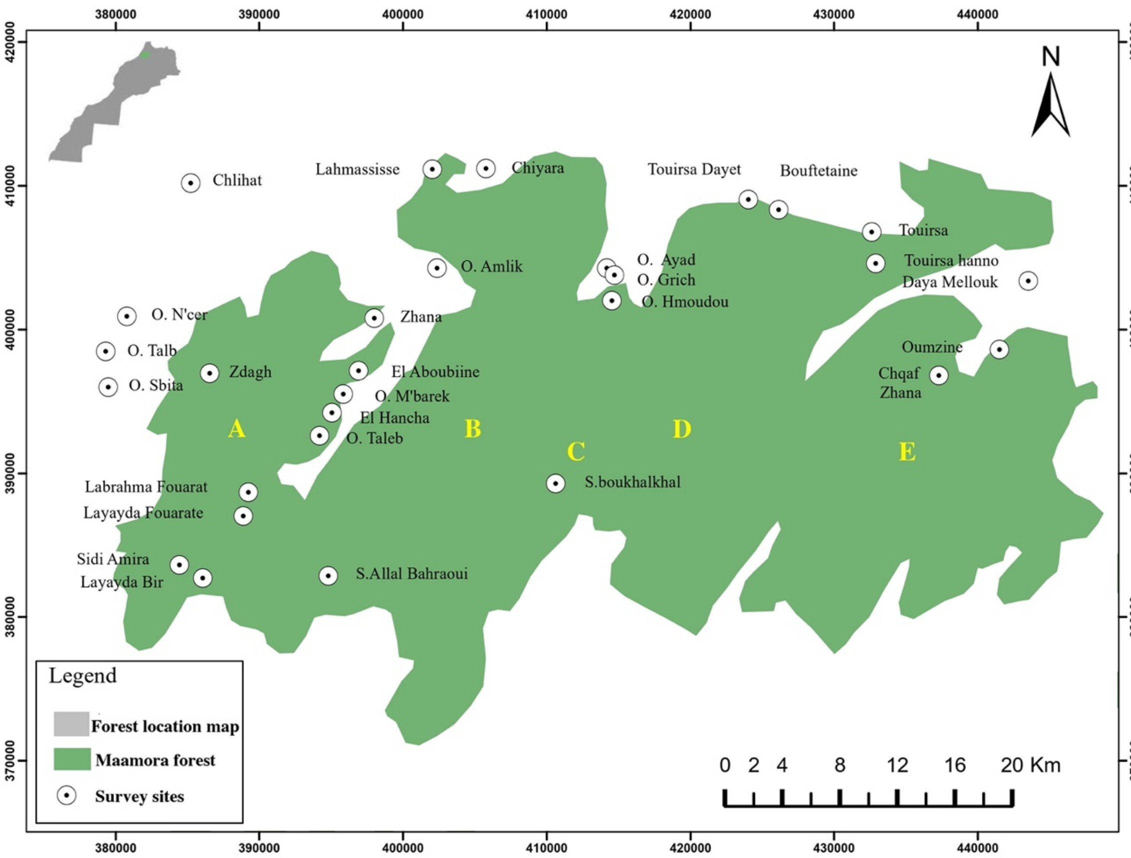

Figure 1. Survey sites repartition within different cantons of Maamora forest (realized by ArcGIS 10.7 software).

Identification of wild mushrooms

Wild mushrooms reported by the participants are identified in the Laboratory of Natural Resources and Sustainable Development, Faculty of Sciences, Ibn Tofail University, Kenitra, Morocco. All specimens were dried, packaged, labeled and preserved in our mycological herbarium.

Statistical analysis and quantitative indices

Statistical analyses were performed using R software version 4.4.2. Descriptive statistics were used to calculate the percentages of the various sociodemographic characteristics. A bivariate analysis, using Pearson's Chi-squared test, was conducted to examine the associations between the use of WMs and each of the sociodemographic variable.

A Multiple Correspondence Analysis (MCA) was then performed to explore the typology of WMs users, considering all sociodemographic variables. To analyze the variations in the uses of WM species reported by inhabitants from 29 sites distributed across the five cantons of the Maâmora Forest (Fig. 1), we employed non-metric multidimensional scaling (nMDS) based on Bray-Curtis dissimilarity distances. Finally, a Permutational Multivariate Analysis of Variance (PERMANOVA) was employed to test the significant influence of cantons on WM use ($p < 0.05$, 999 permutations), using the adonis2 function from the R package 'vegan.'

Quantitative analyses of the data were carried out using ethnobiological indices: Family Use Value (FUV), Cultural importance index (CI), Fidelity level (FL), and Informant Consensus Factor (ICF).

FUV

Importance of fungal families was determined by the FUV. The following formula was applied to determine it (Phillips & Gentry 1993):

$$FUV = \frac{UV_s}{n_s}$$

where UVs is the number of respondents that mention a family and Ns is the total number of species within each family.

CI

CI is more relevant than other indices because it accounts for both the number of informants for each species and the diversity of its uses (Tardío & Pardo-de Santayana 2008). The following formula is used to calculate it:

$$CI = \sum_{u=u_1}^{u_{NC}} \sum_{i=i_1}^{i_N} \frac{UR_{ui}}{N}$$

where:
CI is the cultural importance index for a given species.
UR_{ui} is the number of use reports for use category u by informant i.
^{u}NC is the total number of use categories for the species.
^{i}N is the total number of informants who mentioned the species.
N is the total number of informants in the study.

FL (%)

FL quantifies effectiveness of a species for a use category (Friedman *et al*. 1986). It is calculated as the percentage of people who mention using a specific mushroom for a particular ethnomedicinal use (Np) divided by the total number of informants who mentioned the mushroom for any ethnomedicinal use (N). Calculation formula is:

$$FL = \frac{N_p}{N}$$

ICF

To test homogeneity of traditional knowledge sharing about the use of wild medicinal mushrooms, ICF was used (Heinrich *et al*. 1998). Parameter was calculated as:

$$ICF = \frac{N_{ur} - N_t}{N_{ur} - 1}$$

where: Nur is the number of use reports for a specific use category, and Nt is the number of WMs used for a specific use category.

Results and discussions

Demographic characteristics of interviewees

The results of the chi-square test analysis showed that only gender had a significant ($p < 0.05$) association effect on the use of WMs (Table 1).

Variables	Informant groups	Number of informants (%)	Culinary use	Medicine use	Chi-squared	P Value
Gender	Men	92 (39.0)	62	37	9.004	0.003*
	Women	144 (61.0)	33	51		
Group age	< 15	6 (02.5)	1	1	0.290**	1.000
	16 - 30	21 (08.9)	2	1		
	31 - 44	68 (28.8)	19	17		
	> 45	141 (59.8)	73	69		
Family situation	Single	31 (13.1)	5	6	0.198	0.906
	Married	193 (81.8)	81	74		
	Widower	12 (05.1)	9	8		
Education level	Illiterate	154 (65.2)	74	59	7.226**	0.067
	Primary school	63 (26.7)	17	15		
	Secondary school	12 (05.1)	3	9		
	University	7 (03.0)	1	5		
Employment status	Farmer	40 (16.9)	17	13	9.027**	0.098
	Shepherd	8 (03.4)	0	3		
	WM Merchant	21 (08.9)	10	9		
	Retired	11 (04.7)	2	9		
	Unemployed	153 (64.8)	64	52		
	Forest guardian	3 (01.3)	2	2		
Monthly Income (Dh)	0 DH	153 (64.8)	64	52	2.774	0.428
	500-1000DH	35 (14.8)	11	10		
	1000-2000DH	18 (07.6)	9	8		
	≥ 2000 DH	30 (12.7)	11	18		
Distance from interviewee's house to forest	0 Km	108 (45.8)	51	41	5.482	0.064
	0,1 to 3 Km	118 (50.0)	42	38		
	≥ 7 Km	10 (04.2)	2	9		

Table 1. Demographic characteristics of interviewees and their influence on WM use.

*Significant difference at p = 0.05 level.

** Chi-squared test with a simulated p-value (based on 10,000 replicates) using Monte Carlo.

In a total of 236 informants, 61 % are women and 39 % men (1.56/1 females per male). Gender imbalance in this survey is explained by women's adherence to traditional practices and by the fact that WMs enable them to supplement their diet and manage family illnesses. Similar trends were observed in many regions of the world (Garibay-Orijel *et al*. 2012, López-García *et al*. 2024). In contrast, several studies show that men use WMs more than women, e.g. in China (*Kang et al.* 2013, Wang *et al.* 2022). Many ethomycological studies reveal, however, that gender does not affect the use of WMs (Brown 2019).

Regarding the age, most respondents (59.8 %) were aged over 45, followed by 31-44 (28.8 %), and 16-30 (8.9 %).
The smallest group (2.5%) was under 15. Higher involvement of older interviewees may be due to their greater experience and accumulated knowledge of WM usage over their lifetime (Okui *et al*. 2021). Several studies have reported the strong involvement of older people (Kotowski *et al*. 2019, Łuczaj & Nieroda 2011, Wang *et al*. 2022). Low participation of

respondents aged less than 15 can be explained by a lack of interest for traditional knowledge and increasing opportunities in the industrial field. Additionally, intoxication makes young people fearful of using WMs (López-García *et al*. 2024).
Factor of education level was negatively correlated with the informant's knowledge of WM use. Among the informants, 65.2 % were illiterate, 26.7 % had attended primary school, 5.1 % had completed secondary school, and only 3 % had received higher education. Since most illiterate individuals were involved in agricultural practices and other traditional activities, and considering the dominance of older respondents, who are generally illiterate, this conclusion is similar to López-García *et al*. (2024) results. In Indonesia, WMs are collected and used more by educated informants than illiterate people (Yusran *et al*. 2024). However, Haro-Luna *et al*. (2022) found no correlation between individuals' education levels and their traditional knowledge.

Most of our informants are unemployed (64.8 %), farmers (16.9 %), or WM merchants (8.9 %). Additionally, 4.7 % are retired, 3.4 % shepherds, and only 1.3 % forest guardians. In fact, unemployed individuals have the time to collect WMs.

Most gatherers live within the forest (45.8 %) or very close (0.1 to 3 km) to it (50 %), with only 4.2 % living more than 7 km away. This finding is confirmed by several studies, including that of Yusran *et al*. (2024). Regular presence in the forest, due to agricultural and foraging activities, exposes them more to WMs, providing them with more developed traditional mycological knowledge compared to communities situated farther (Boni & Yorou 2015). Milenge Kamalebo and De Kesel (2020) observed that limited local interest in mushrooms is due to long distance from their habitat and collection site.

Typology of WMs users based on sociodemographic variables
The multiple correspondence analysis (MCA) of the variables revealed that the first and third dimensions alone account for 24.71% of the total inertia. This allows us to classify all the modalities into four distinct groups (Fig. 2a & 2b):

Group 1 predominantly comprises women who are unemployed and have no monthly income, with a majority being aged 45 and over and having no formal education. These individuals frequently use WMs for culinary purposes, especially *Terfezia arenaria* and *Boletus* sp. They rarely use mushrooms for medicinal purposes, exploiting species *Terfezia arenaria* and *Boletus* sp or *Terfezia arenaria* alone. In contrast, this demographic is underrepresented among men, shepherds, and individuals with a monthly income ranging from 500 to 1000 DH. This demographic is further characterized by individuals with a primary level of education, those within the 16 to 30 age, and single people. Notably, culinary use is prevalent in this group for species *Boletus* sp.

Group 2 consists primarily of male farmers within a radius of 0.1 to 3 km from the forest. Their monthly income is typically between 500 and 1000 DH or occasionally between 1000 and 2000 DH. These individuals primarily use *Boletus* sp. for medicinal purposes, followed by the medicinal use of *Terfezia arenaria*, which are also used less frequently for culinary purposes. This group shows a low frequency of both culinary and medicinal use of *Pleurotus ostreatus*. The demographic composition of this group is characterized by the underrepresentation of single male farmers aged 16 to 30, and those with an income between 500 and 1000 DH, who primarily use *Tuber oligospermum* for medicinal purposes, followed by its culinary use.
Group 3, which is poorly represented, comprises female, unemployed, and illiterate individuals aged 45 and above, who are either married or widowed. These individuals use *Cantharellus cibarius* and *Terfezia arenaria* for both medicinal and culinary purposes.

Group 4 consists of illiterate individuals, either unemployed or working as forest guards, aged 45 and above, and living in close proximity to the forest. They are underrepresented in the overall sample. These individuals use *Pisolithus sp.* specie for medicinal purposes.

Dissimilarity in the use of WMs across the cantons of the Maâmora Forest
The Shepard plot obtained from nMDS (Fig. 3a) indicates a strong correlation between observed dissimilarity and ordination distance (R^2=0.987). This strong correlation attests to the reliability of the adjustment carried out by the nMDS method. Furthermore, the low stress value (0.115) confirms the quality of the adjustment made by the nMDS. Collectively, these analyses highlight the robustness and effectiveness of the method employed in this study.

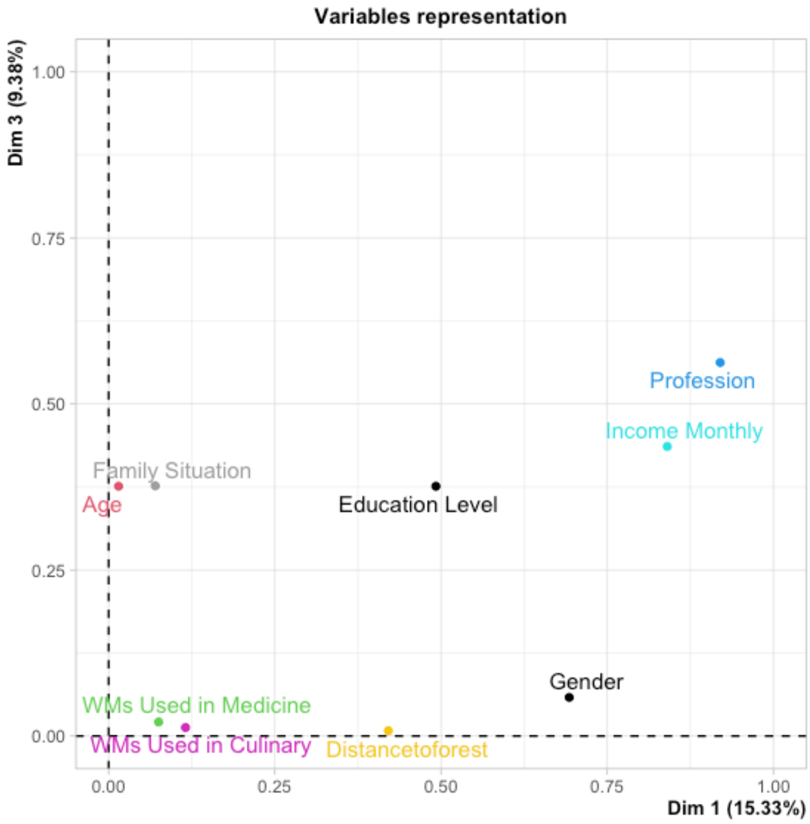

Figure 2a. Mapping of categorical variables

The nDMS analysis (Fig. 3b) indicates that the use of certain WMs is closely associated with specific cantons. for example, *Pisolithus* sp. is used exclusively in canton D, while *Amanita caesarea* is unique to canton B. The mushrooms *Pleurotus ostreatus* and *Cantharellus cibarius* are commonly used in cantons A and B. Meanwhile, the overlapping central ellipses indicate that several mushrooms, such as *Boletus* sp. and *Tuber oligospermum,* are shared among cantons A, B, C, and D, highlighting similarities in their use across these cantons. Notably, *Terfezia arenaria* is used in all cantons.

The results in the Table 2 indicate a significant relationship between mushroom distribution and cantons ($P < 0.05$). This suggests that the distribution of mushroom species is not random but is influenced by factors specific to each canton.

Species diversity and cultural importance of wild mushrooms

The study incorporated scientific names, families, use categories and various indexes such as FC, UR, CI, and FUV. (Table 3)

Our results showed that local community of study area used seven macro-fungi, including two ascomycetous species and five basidiomycetous, belonging to 7 families and 7 genera. Each family contained only one species. Terfeziaceae (FUV= 0.475), Boletaceae (FUV= 0.394) were the most frequently recorded based on the FUV index (Fig. 4). Their prevalence may be attributed to favorable ecological conditions and their higher economic value. In contrast, Pleurotaceae (FUV = 0.115), Cantharellaceae (FUV = 0.085), Tuberaceae (FUV = 0.076), Pisolithaceae (FUV = 0.030) and Amanitaceae (FUV = 0.004) were less frequently recorded. Predominance of Terfeziaceae in our study is consistent with finding in Algeria (Bradai *et al*. 2015), and of Boletaceae with studies by Wang *et al*. (2022) in China.

Interestingly, *Terfezia arenaria* has the highest CI (Table 3), with the greatest value attributed to its medicinal and culinary uses (CI_{med} = 0.258 and CI_{cul} = 0.216, respectively). *Boletus* sp. is also highly used by the population of the study area. This species is mainly used for food (CI_{cul} = 0.212), and medicinal purposes (CI_{med} = 0.182) (Table 3). In contrast, *Pleurotus ostreatus* shows low CI_{cul} and CI_{med} values (0.064 and 0.051, respectively). Similarly, *Cantharellus cibarius* and *Tuber oligospermum* also have low CI values, with culinary uses being the most significant (CI_{cul} = 0.047 and 0.042, respectively), followed by medicinal uses (CI_{med} = 0.038 and CI_{med} = 0.034, respectively). *Pisolithus* sp. is used exclusively for therapeutic purposes, with a CI_{med} = 0.030. Finally, *Amanita caesarea* has a very low cultural importance index (CI_{cul} = 0.004) and retains insignificant value across all examined categories.

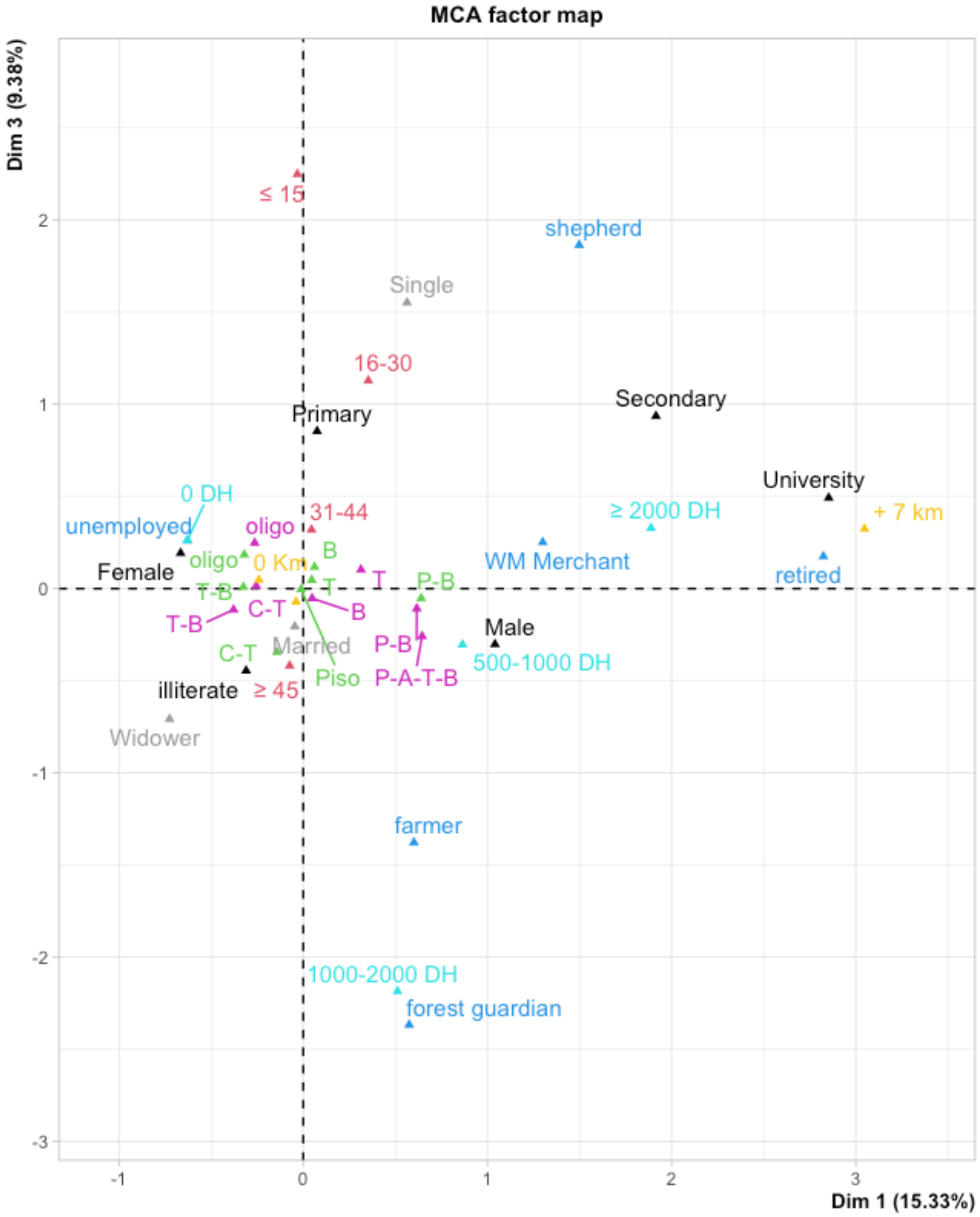

Figure 2b. Graphical representation of Multiple Correspondence Analysis (MCA)
Legend*: A: Amanita cesarea,* B*: Boletus* sp.*,* C*: Cantharellus cibarius,* oligo*:Tuber oligospermum,* P: *Pleurotus ostreatus, Piso: Pisolithus* sp. *,* T*: Terfezia arenaria.* Each category (fig2b) has the same color as its variable (fig2a).

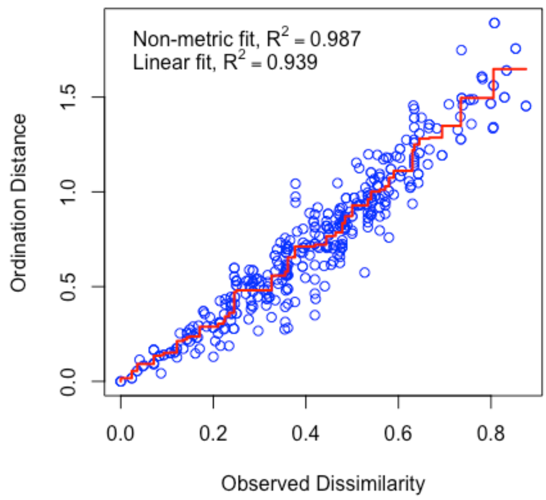

Figure 3a. Shepard stress plot illustrating the relationship between nMDS ordination distance and the original observed distance.

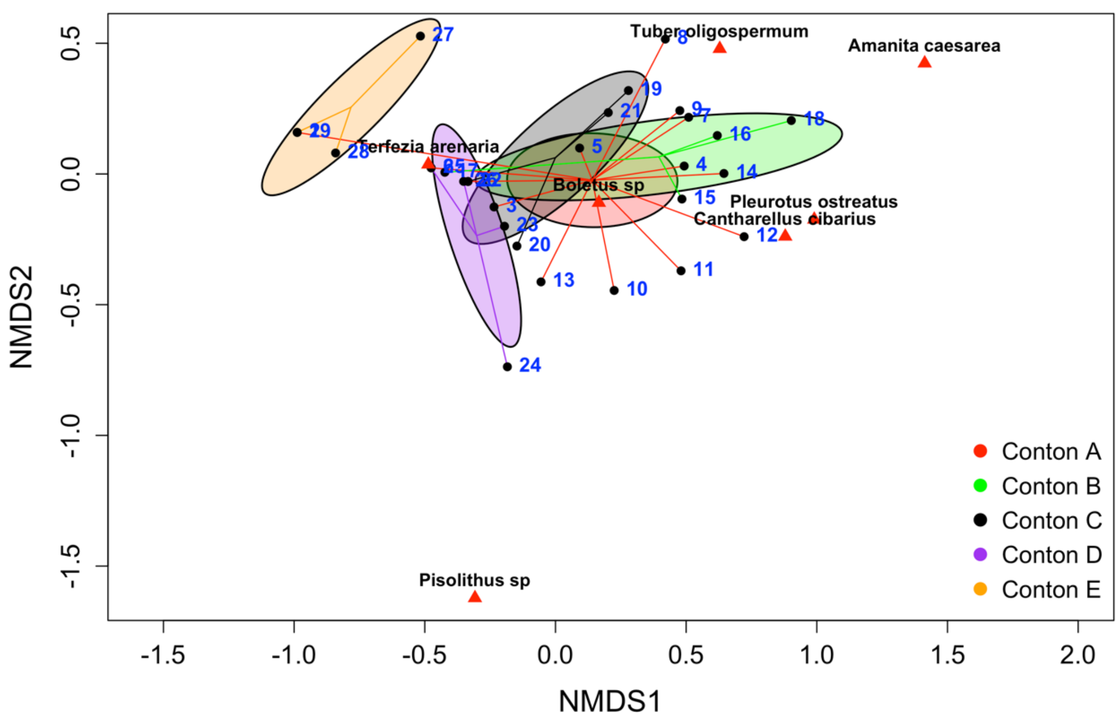

Figure 3b. Non-Metric Multidimensional Scaling (nMDS) Graph based on the Bray-Curtis method

Table 2. Results of the PERMANOVA analysis.

WMs	degrees of freedom	Sum of squares	R^2	F-Value	P-Value
Cantons	4	0.8516	0.26911	2.2092	0.027*
Residual	24	2.3130	0.73089		
Total	28	3.1647	1.00000		

*Significant difference at p = 0.05 level.

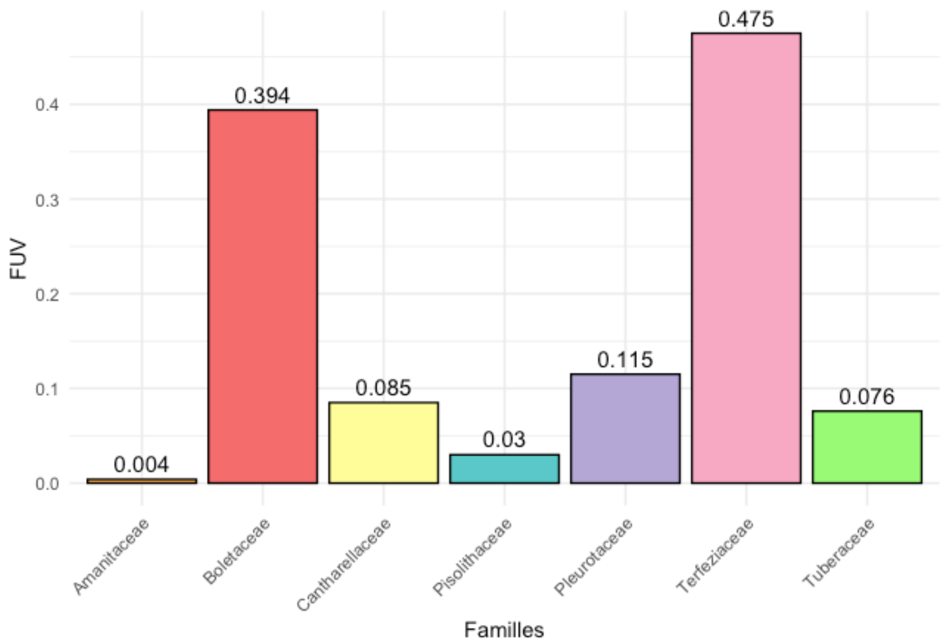

Figure 4. Family use value (FUV) of edible and medicinal mushrooms.

Table 3. List of mushroom species used in Maamora Forest.

Family/ Scientific name	**UR**		**CI**		**FC**	**FUV**
	Cul.	**Med.**	**Cul.**	**Med.**		
Amanitaceae						0.004
Amanita caesarea Pers	1	-	0.004	-	1	
Boletaceae						0.394
Boletus sp. *Section Edules*	50	43	0.212	0.182	93	
Cantharellaceae						0.085
Cantharellus cibarius Fries	11	9	0.047	0.038	20	
Pisolithaceae						0.030
Pisolithus sp.	-	7	-	0.030	7	
Pleurotaceae						0.115
Pleurotus ostreatus (Jacq.) P. Kumm.	15	12	0.064	0.051	27	
Terfeziaceae						0.475
Terfezia arenaria (Moris) Trappe	51	61	0.216	0.258	112	
Tuberaceae						0.076
Tuber oligospermum (Tul. & C. Tul.) Trappe	10	8	0.042	0.034	18	

UR: Use category; CI: Cultural importance index; Cul.: Culinary; Med.: Medicine; FUV: family use value.

The highest CI was recorded for *Terfezia arenaria*, which has wide acceptability worldwide due to its organoleptic qualities (Tejedor-Calvo *et al*. 2021). This species has also been identified as the most used fungal species in different regions (Abourouh 2020, Bradai *et al*. 2015, Khabar 2002). Similar reasons apply to *Boletus* sp. It has been identified as a highly utilized fungal species in different regions (Nincević Runjić *et al*. 2024, Wang *et al*. 2022).

In contrast to our study, several investigations have indicated that *Amanita caesarea* and *Cantharellus cibarius* are regarded as the most culturally significant species (Montoya *et al*. 2003). Low *Cantharellus cibarius,* and *Amanita caesarea* CI can be explained by their scarcity in the Maamora forest, as noted by informants and as reported in other parts of the world (Arnolds 1991). This observation highlights the urgency of conducting ecological studies to identify the factors responsible for the disappearance tendency of these fungi.

Low *Pisolithus* sp. CI is explained by the fact that this mushroom is used only by one local community, known as Bouftetaine, among all the Douars surveyed in the forest. This use, which was once likely common among many villagers, is now reported by only seven individuals in one village, reflecting the decline of interactions between the people and mushrooms.

Overall, the species of wild mushrooms reported by the present ethnomycological research are valued principally for their significant contribution to their use as food and for their traditional medicinal applications, as reported by Molares *et al*. (2020), except for *Pisolithus* sp..

Income generation by WMs use category

The results show that the inhabitants of the Maâmora forest generate significant income from selling WMs (Table 4).
These incomes are primarily derived from dual-use species, meaning culinary and medicinal. For instance, *Terfezia arenaria* (50.4%) and *Boletus* sp. (47.9%) are among the most commercialized species. Similarly, *Tuber oligospermum* shows a notable sales frequency (28.4%).
Other dual-use species make a more modest contribution, such as *Cantharellus cibarius* (11.0%) and *Pleurotus ostreatus* (8.5%), which reflects some variability in the availability or demand for these mushrooms, particularly chanterelles, in the specific ecological context of the Maâmora forest.

In contrast, species used exclusively for culinary purposes, such as *Amanita caesarea* (1.7%), show a marginal economic contribution. Similarly, *Pisolithus* sp. was reported solely for medicinal use and is not commercialized.

Table 4. list of mushroom species generate income in Maamora Forest.

Scientific name	**Use category ***	**Number informants reporting sale**	**Frequency of Sale (%)**
Amanita caesarea Pers	Culinary	4	1.7 %
Boletus sp. *Section Edules*	Culinary, Medicinal	113	47.9 %
Cantharellus cibarius Fries	Culinary, Medicinal	26	11.0 %
Morchella sp.	No local use	11	4.7 %
Pisolithus sp.	Medicinal	-	-
Pleurotus ostreatus (Jacq.) P. Kumm.	Culinary, Medicinal	20	8.5 %
Terfezia arenaria (Moris) Trappe	Culinary, Medicinal	119	50.4 %
Delastria rosea Tul. & C.Tul	No local use	49	20.8 %
Tuber asa Tulasne	No local use	34	14.4 %
Tuber oligospermum Tul. & C. Tul.) Trappe	Culinary, Medicinal	67	28.4 %

* Are derived from the data in Table 3

Some species with no locally reported use are nonetheless sold. This is the case for *Delastria rosea* (20.8%), *Tuber asa* (14.4%), and *Morchella* sp. (4.7%). This observation suggests the existence of trade circuits oriented toward external markets, where these mushrooms are recognized for culinary, medicinal, or other values that differ from local perceptions.

These findings are consistent with studies from other regions, where WMs generate income and ensure subsistence for people who are unemployed (Zhu *et al*. 2019), creating financial capital that has a positive impact on their social status and livelihoods. According to Arora (2008) study, in China, matsutake income per household (2 to 5 pickers) varies between ¥12,000 and ¥60,000 / 2 months (USD 1,674.04 - 8,370.18). Several studies have also highlighted the specific economic value of species identified in our research. *Terfezia arenaria* is widely recognized as a generator of income (Tejedor-Calvo *et al*. 2021), similar reasons apply to *Boletus* sp. (Cai *et al*. 2011). *Amanita caesarea*, and *Cantharellus cibarius* (Montoya et al., 2003). Other research also confirms the active commercialization of *Morchella* sp. (Molares *et al*. 2020; Montoya *et al*. 2003).

Thus, this analysis highlights that, in the Maâmora forest, incomes derived from WMs are primarily based on their culinary use, while medicinal use, although acknowledged, plays a secondary and often complementary role in local trade. This finding aligns with other contexts where gastronomic value remains the primary driver of wild mushroom commercialization.

Culinary uses and preservation methods of WMs

The present study reports culinary use of six mushrooms (Table 5): *Amanita caesarea*, *Boletus* sp., *Cantharellus cibarius*, *Pleurotus ostreatus*, *Terfezia arenaria*, and *Tuber oligospermum*, all of which have a Final Edibility Status (FES) of E1: Edible, confirmed (Li *et al*. 2021). This explains the 100 % response rate of *"no"* to the question regarding *"problems after consumption of the wild edible mushrooms"*. These mushrooms are consumed because of their culinary value. Several previous studies have also shown that macro-fungi are mainly used as food (Ríos-García *et al*. 2023).

Used mushroom parts and development stages

The study revealed that inhabitants consumed all parts of the mushroom's fruiting bodies, both in young and mature stages (Table 5), as reported in Serbia by Zivkovic *et al*. (2021). This differs from local people in Pakistan, who collected only WEMs at the mature stage (Hussain *et al*. 2023), while only tubes and context were used by the people of P'urhépecha, Mexico (Torres-Gómez *et al*. 2023).

According to respondents, mushrooms are boiled for a short time before any preparation to remove mainly sand particles as well as insect larvae, as reported by Ninčević Runjić *et al*. (2024). Water used for boiling should be removed, as reported in Serbia by Zivkovic *et al*. (2021). As stated by survey participants, WEMs are consumed to replace meat. This observation is recognized worldwide (Torres-Gómez *et al*. 2023), due to their nutritional value, texture, and flavor.

Recipes and preparation methods

There is a variety of dishes based on local ingredients, showcasing the rich culinary heritage of the Maamora forest communities. The most popular dish that used mushrooms among respondents was "Tagine", a typical Moroccan dish prepared in different ways, using different ingredients and mushrooms, as indicated in Table 5. In addition, *Tuber oligospermum* is often added to "Rfissa", another traditional dish.

Utilization of *Pleurotus ostreatus* in soups is the same as by people of Pamona in Indonesia (Yusran *et al*. 2024). Use of truffles in "Tagine" with lamb was documented by Abourouh (2020) and Khabar (2002), in our study area, as well as in some communities of Algeria by Bradai *et al*. (2015).

Some culinary practices that differ from those in our study are as follow: *Pleurotus ostreatus* is often incorporated into sauces (Hussain *et al*. 2023), *Cantharellus cibarius* into salads, frying or boiling with vegetables (Zivkovic *et al*. 2021), while *Boletus* sp. is cooked with salt and chili (Torres-Gómez *et al*. 2023), with potatoes or fried in butter for soups (Hussain *et al*. 2023), and desert truffles are used in couscous dishes in Algeria (Bradai *et al*. 2015) and are prepared similarly to meat in the Middle East (Bokhary *et al*. 1990). As noted by Pérez-Moreno *et al*. (2021), this diversity illustrates the necessity of conserving both traditional practices and the forest that supports the WEMs.

Methods of preservation

In current investigations, mushrooms consumed by the local forest population (Fig. 5) are used in their fresh form (69.70 %). As previously reported (Hussain *et al*. 2023), this preference for fresh mushrooms likely stems from their immediate availability and optimal preservation of their nutrients and flavors.

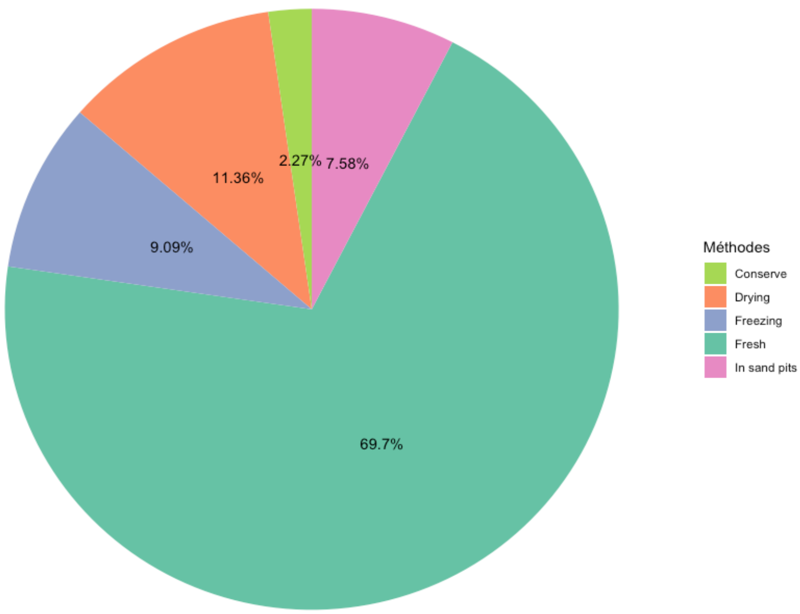

Figure 5. Forms of wild edible mushroom use.

Table 5. Uses and preparation methods of wild mushrooms in the Maamora Forest.

Scientific name	Parts used	Young or Mature	Culinary use: Local preparation Method	Culinary use: Local preparation recipes	Ethnomedicinal use (UR): Utilization way	Ethnomedicinal use (UR): Use traditional (UR)	FL (%)
Amanita caesarea Pers	Fruiting body	Both	Not known	None	-	-	-
Boletus sp. *Section Edules*	Fruiting body	Both	Boiled	Cooked in tagine with tomatoes and eggs (substitute for meat) (UR = 30)	By consuming By consuming By consuming	Anti-cold (UR=27) Immune system strengthening (UR=14) Coughs (UR = 2)	62,8
Cantharellus cibarius Fries	Fruiting body	Both	Boiled	Cooked in tagine with tomatoes and eggs (substitute for meat) (UR = 9)	By consuming	Immune system strengthening (UR=9)	100
Pisolithus sp.	Fruiting body	Mature	-	-	Applied as powder to baby's buttocks (UR =7)	Diaper rash (UR = 7)	100
Pleurotus ostreatus (Jacq.) P. Kumm.	Fruiting body		Boiled	Cooked in tagine with peas (UR= 5); Preserving liquid added to dishes with lentil (UR = 1); In soup mixed with other vegetables (UR=4)	By consuming By consuming	Anti-cancer (UR = 2) Immune system strengthening (UR=10)	83,3
Terfezia arenaria (Moris) Trappe	Fruiting body	Both	Boiled	Cooked in tagine with tomatoes and eggs (substitute for meat). (UR= 57); Cooked in tagine with potatoes and peas (substitute for meat) (UR=12); Cooked with eggs, parsley, ail and spices (substitute for meat) (UR=15); Lamb tagine with truffles (UR=10)	Applied as few drops of juice to eyes (UR = 29) By consuming By consuming By consuming By consuming	Eye disease (UR = 29) Immune system strengthening (UR=19) Anti-cancer (UR = 7) anti-cold (UR = 4) Sexual stimulant (UR=2)	47,5
Tuber oligospermum (Tul. & C. Tul.) Trappe	Fruiting body	Both	Boiled	Added to Rfissa (substitute for meat) (UR =8)	By consuming	Immune system strengthening (UR=8)	100

FL: Fidelity level, UR: number of informants citing the fungi for use.

Preservation methods include sun drying (11.36 %), followed by freezing (9.09 %), storage in sand pits (7.58 %), and canned form (2.27 %).

Respondents reported the latter method for *Pleurotus ostreatus*. Mushrooms are first cleaned and sliced into strips, placed in jars, and cooked in a pressure cooker filled with water for 45 minutes. After cooling, they are stored in the refrigerator for year-round. Cooking liquid is also collected and used in various culinary preparations. All these conservation methods are used in several regions of the world (Wang *et al*. 2022). Storing mushrooms in sand pits, while less frequent, is a natural method to protect desert truffle species (*Terfezia arenaria*, *Tuber asa*, and *Tuber oligospermum*). This method was documented by Abourouh (2020).

Medicinal species, remedy preparation, and cultural relevance of WMs

The present study identified six wild medicinal mushrooms: *Boletus* sp., *Cantharellus cibarius*, *Pisolithus* sp., *Pleurotus ostreatus*, *Terfezia arenaria* and *Tuber oligospermum* (Table 5, Fig. 6). This number is greater than the two species found by López-García *et al*. (2024) and the five species noticed by Ríos- García *et al*. (2023) in Oaxaca, Mexico. Nevertheless, it is less than the eight species reported in Pakistan (Hussain *et al*. 2023).

Figure 6. Wild mushrooms used in Maamora forest

(a): Cantharellus cibarius, (b): Amanita caesarea Pers*, (c): Boletus sp. Section edules, (d): Pleurotus ostreatus, (e): Terfezia arenaria, (f): Tuber oligospermum, (g): Pisolithus* sp*.*

Fidelity level of wild medicinal mushrooms

Data assessment revealed that the FL value is ranged from 47.5 to 100 %. Three wild medicinal mushrooms were identified with a FL of 100 %: *Cantharellus cibarius*, *Tuber oligospermum*, and *Pisolithus* sp., which are used to strengthen the immune system and as diaper rash, respectively. This reflects agreement of informants on the efficacy of these wild medicinal mushrooms for their specific uses. Prakofjewa *et al*. (2024) report also that *Cantharellus cibarius* is used to strengthen the immune system. The lowest FL value (Table 5), 47.5 %, was recorded for *Terfezia arenaria*, which possesses several medicinal effects, including treatment of eye disease, strengthening the immune system, as anti-cancer, anti-cold, and sexual stimulant, as cited in the previous research by Abourouh (2020), Bradai *et al*. (2015) and Mandeel (2007). The use of *Cantharellus cibarius* by the inhabitants of the Maamora forest to strengthen the immune system can be attributed to its richness in bioactive compounds (polysaccharides, cibaric acid and phenolic compounds as gallic acid) responsible for nematicidal, antimicrobial, antioxidant, antifungal, anti-inflammatory and anticancer properties (Nincević Runjić *et al*. 2024, Zhou *et al*. 2024). These properties also explain the diverse use of this species, mainly as an antibacterial and anticancer (Prakofjewa *et al*. 2024). *Terfezia arenaria* and *Tuber oligospermum* exhibit therapeutic properties, such as antioxidant, anti-inflammatory, antimicrobial, and immunoenhancing effects due to their phenolic compounds, beta-glucans, gallic acid, and tocopherols (Tejedor-Calvo *et al*. 2021). Furthermore, *Terfezia arenaria* contains in addition polysaccharides and sterols related to anticancer activities (Tejedor-Calvo *et al*. 2021).

Methods of remedy preparations

Method of extracting *Terfezia arenaria* juice involves washing the fresh truffle and opening it from the top, placing it over a low heat and using a syringe to withdraw the necessary amount of liquid, allowing the juice to cool, and then applying a few drops to eyes. A similar method was reported by Abourouh (2020), Shavit and Shavit (2014) and Volpato *et al*. (2013).

For *Pisolithus* sp., gleba is removed and the brown powder (spores) collected. This powder is applied by rubbing it onto the baby's buttocks.

It should be noted that answer to the question *"the use as veterinary"* was negative by all informants. To treat uterine and external inflammations in livestock, Sahara inhabitants (Sahrawi) use boiled desert truffles (Volpato *et al*. 2013).

Therapeutic uses and informant consensus factor of wild medicinal mushrooms

Informant consensus factor measures the degree of agreement among different informants concerning the use of wild medicinal mushrooms for treating specific category of ailments (Heinrich *et al*. 1998).

In our study, seven categories were reported (Table 6): anticancer, immune system strengthening, anti-cold, eye disease, diaper rash, coughs and flu, and sexual stimulants, with ICF ranging from 0.875 to 1. Ailments with the highest value (ICF = 1) were eye disease, coughs and flu, diaper rash and sexual stimulants, followed by anti-cold (IFC = 0.967) and immune system strengthening (ICF = 0.932). Anticancer has the lowest ICF (0.875). *Terfezia arenaria* (29 citations), *Pisolithus* sp. (7 citations), *Boletus* sp. (2 citations) and *Terfezia arenaria* (2 citations) were used to treat eye disease, diaper rash, coughs and flu and as sexual stimulants, respectively.

For anti-cold, *Boletus* sp. (27 citations) and *Terfezia arenaria* (4 citations) were reported. *Terfezia arenaria* (19 citations), *Boletus* sp. (14 citations), *Tuber oligospermum* (8 citations), *Pleurotus ostreatus* (10 citations), and *Cantharellus cibarius* (9 citations) were cited for immune system strengthening. *Terfezia arenaria* (7 citations) and *Pleurotus ostreatus* (2 citations) were reported for anticancer purposes. These results reflect that local population of Maamora forest can match each illness with its fungal remedy. *Terfezia arenaria* was the most used fungi to remedy eye disease by people living in or around this forest. It was the most commonly mentioned among Sahrawi and populations in the Arabian Peninsula (Volpato *et al*. 2013), the Middle East and North Africa (Shavit & Shavit 2014).

Local population of Maamora forest has a saying about truffles: *"Eating truffles and wearing warm clothes protects you from the cold, especially in the dead of winter"*. The high ICF values suggest that respondents are reliable in their use of wild medicinal mushrooms (Lin *et al*. 2002). Thus, all these species should be prioritized for pharmacological and chemical research.

Poisoning

Our surveys revealed no cases of mushroom poisoning or intoxication in the study area. However, fear of toxic mushrooms persists. The same observation was made by Zeleke *et al*. (2020). All informants indicated that they only used species they knew well.

"During my surveys, when I showed a Cantharellus cibarius to an informant under the age of 15, he told me it was toxic because his father had explained to him that all yellow mushrooms were poisonous". This mastery of knowledge about useful mushrooms is mentioned in several studies (Rammeloo & Walleyn 1993).

A visit to the Moroccan Poison Control Center and Pharmacovigilance (CAPM) revealed two cases of mushroom poisoning in the Maamora forest: Case 1 corresponds to a poisoning by *Amanita pantherina*, involving two girls from Kenitra city, 2 and 12 years old. The family was in a picnic in the forest, where the girls picked and consumed this poisonous fungus. In case 2, intoxication was by white truffles of a 30 year old woman, also from Kenitra city. These poisoning cases can be explained by the fact that mycological knowledge in urban areas is very limited (Rammeloo & Walleyn 1993). Many cases of poisoning by *Amanita pantherina* have been reported worldwide, e.g. 10 recorded in United States between 2002 and 2016 (Moss & Hendrickson 2019). Only one case of truffle intoxication, reported by Leport (1995), is known. This intoxication could be explained by contamination of mushrooms during preparation or by digestive intolerance developed by consumers.

Table 6. ICF values by therapeutic category.

Category	Wild Mushrooms species used and number of citations	Nt	Nur	ICF
Anticancer	*Terfezia arenaria* (7), *Pleurotus ostreatus* (2).	2	9	0,875
Immune system strengthening	*Terfezia arenaria* (19), *Boletus sp. Sect Edules (*14). *Pleurotus ostreatus* (10), *Cantharellus cibarius* (9). *Tuber oligospermum* (8).	5	60	0,932
Anti-cold	*Boletus* sp. (27), *Terfezia arenaria* (4).	2	31	0,967
Eye disease	*Terfezia arenaria* (29).	1	29	1,000
Diaper rash	*Pisolithus* sp. (7).	1	7	1,000
Coughs and flu	*Boletus* sp. (2).	1	2	1,000
Sexual stimulants	*Terfezia arenaria* (2).	1	2	1,000

Nur = the number of use reports for a specific use category, Nt = the number of WMs used for a specific use category.

Conclusion

Our quantitative ethnomycological survey, the first of its kind in Moroccan Maamora forest, revealed that populations surveyed use wild mushrooms primarily to generate revenue, as well as for their nutritional and therapeutic values.

This study documented methods of conservation, traditional preparation, and application steps for edible and medicinal wild mushrooms, which had never been recorded in previous research, as well as intoxication cases. Thereby, it contributes to the preservation of traditional knowledge handed down from generation to generation. It also serves as a primary database for future ethnomycological research.

This work emphasizes ecological studies importance on species with a low CI index to identify the factors responsible for their extinction tendency and proposal of solutions for protecting their natural habitats. Furthermore, an analysis of the nutritional composition of the edible mushrooms identified, as well as the pharmacological and mycomedicinal properties of medicinal ones, particularly *Pisolithus* species, could open new application prospects, particularly in cosmetics industry.

Most mushrooms mentioned are consumed and highly appreciated worldwide, namely *Amanita caesarea* (queen of mushrooms), *Boletus* sp. (king of mushrooms), *Cantharellus cibarius* (golden chanterelle), *Pleurotus ostreatus* (oyster mushroom, third most consumed mushroom in the world), and the famous *Terfezia arenaria* (desert truffle).

Research should focus also on domestication to ensure sustainability and reduce pressure exerted by harvesting, especially for high CI income species.
A socio-economic study is also recommended for the species identified for commercial use.
Finally, special attention must be paid to toxicology, particularly for poisonous *Amanita* species, to prevent risk of intoxication and raise public awareness, particularly in recreational areas.

Declarations

List of abbreviations: CI: Cultural importance index; FL: Fidelity level; ICF: Informant Consensus Factor; NTFPs: non-timber forest products; WEMs: wild edible mushrooms; WMs: Wild mushrooms.
Ethics approval and consent to participate: All participants provided oral prior informed consent.
Consent for publication: Not applicable

Availability of data and materials: Not applicable
Competing interests: The authors declare that they have no competing interests
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Author contributions: Anas Fellaki: Writing - review & editing, Writing - original draft, Investigation, Conceptualization. Atmane Rochdi: Supervision, Conceptualization. Houda Elyacoubi: Supervision, Conceptualization. Asmaa Elyamani: Writing - Review & Editing. Mohamed Abourouh: Writing - Review & Editing, Visualization, Supervision, Conceptualization.

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