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Ethnoecology of desert truffles hunting: A cross-cultural comparative study on practices and perceptions in the Mediterranean and the Near East

Mousaab Alrhmoun [a,b], Naji Sulaiman [b,*], Giulia Mattalia [c], Hiwa M. Ahmed [d], Chadi Khatib [e], Yeter Yeşil Cantürk [f], Giovanni Zucca [b], Abdelkader Ammam [g], Mushtaq Ahmad [h], Andrea Pieroni [b,i]

[a] Faculty of Agricultural, Environmental and Food Sciences, Free University of Bolzano, Piazza Università 5, 39100, Bolzano, Italy
[b] University of Gastronomic Sciences, Piazza Vittorio Emanuele, 9, 12042, Pollenzo, Italy
[c] IMBE, Aix Marseille Université, Avignon Université, CNRS, IRD, Marseille, France
[d] Bakrajo Technical Institute, Sulaimani Polytechnic University, Slemani, Kurdistan Region, Iraq
[e] Manara University, Latakia, Syria
[f] Istanbul University, Faculty of Pharmacy, Istanbul, Turkey
[g] Department of Biology, Faculty of Science, Dr Moulay Tahar University, Saida, 20000, Algeria
[h] Department of Plant Sciences, Quaid-i- Azam University Islamabad, Pakistan
[i] Department of Medical Analysis, Tishk International University, Erbil, 44001, Iraq

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ABSTRACT

This study investigates desert truffle hunting practices across Iraq (including the Kurdistan Region), Eastern Turkey, Syria, and Sardinia (Italy) based on data collected with semi-structured interviews from 58 hunters in 21 locations distributed across the four countries. Employing both Principal Component Analysis and qualitative analysis, the research focuses on ecological, cultural, and economic dimensions of traditional desert truffle hunting/foraging in the Mediterranean and the Near East. The study demonstrates diverse ecological contexts and cultural practices, revealing the reliance on natural indicators for truffle detection and the cultural significance of this practice. Additionally, novel findings highlight the various perceived threats faced by desert truffle ecosystems, including soil erosion, land use patterns, market dynamics, climate change, and threats associated with desert truffle hunting across conflict zones. The study emphasizes the economic contributions of truffle harvesting to local communities, shedding light on its significance for rural livelihoods. Truffles are a traditional medicine for vision disorders, as well as cooking and snack food. By providing comprehensive insights into these multifaceted aspects, this study enhances our understanding of desert truffle hunting's ecological, cultural, and economic importance and informs actionable steps for biocultural conservation, as well as sustainable development initiatives in truffle-rich regions globally.

1. Introduction

Desert truffles, scientifically classified within the *Terfezia, Tirmania, Picoa, Eremiomyces, Mattirolomyces* genera of the Pezizaceae family, are edible hypogeous fungi that thrive in arid and semi-arid regions (Chevalier, 2013; Shavit, 2014; Farag et al., 2021; Morte et al., 2021). The first evidence of the use of desert truffles, which have nourished populations in the in the old world's arid and semiarid areas throughout history, is found among the oldest records of human culture. Desert truffles were coveted by the Bronze Age Amorites in ancient Syria in the second millennium BC. It was also mentioned in the Bible, discussed by the Classic Greeks and Romans, and Islam's Prophet Muhammad recommended their medicinal use (Shavit, 2014). Desert truffles belong to the same class of the European forest truffles (Ascomycetes), but exhibit a unique biological context. While they were previously classified entirely within the Terfeziaceae family, molecular analyses have revealed that some species should be more accurately placed within the Pezizales order, specifically in the Pezizaceae family (Farag et al., 2021).

* Corresponding author.
E-mail addresses: Mousaab.AlRhmoun@unibz.it (M. Alrhmoun), n.sulaiman@unisg.it (N. Sulaiman), giulia.mattalia@uab.cat (G. Mattalia), hiwa2009@yahoo.com (H.M. Ahmed), chadi.khatib@manara.edu.sy (C. Khatib), yesily@istanbul.edu.tr (Y. Yeşil Cantürk), gzucca93@gmail.com (G. Zucca), vetokadi@yahoo.fr (A. Ammam), mushtaq@qau.edu.pk (M. Ahmad), a.pieroni@unisg.it (A. Pieroni).

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Desert and forest truffles share the characteristic of being underground fungi, forming symbiotic relationships with host plants. However, desert truffles are not parasitic as they engage in a mutualistic association with certain plants (e.g. *Cistaceae* spp.), contributing to nutrient exchange and ecological balance. This symbiotic relationship is crucial for their growth and development, allowing them to thrive in challenging environments (Owaid, 2018; Morte et al., 2021).

Desert truffles predominantly thrive in sandy soils (Bonifacio and Morte, 2013), with well-known species like those from the genera *Terfezia* and *Tirmania* typically favouring high pH calcareous soils (Bradai et al., 2015a; Ferreira et al., 2023). However, other species can also be found in soils with acidic pH levels (Bordallo et al., 2015). These truffles have modest water requirements (Turgeman et al., 2011). The presence and abundance of truffles are influenced by various environmental conditions, including rainfall, soil type, and climatic patterns (Andrino et al., 2019); rainfall amount and distribution during the rainy season are the primary determinants of wild yields. Adequate yields can often be achieved with as little as 200–250 mm of rainfall per season (Bradai et al., 2015a). On the contrary, drought and soil degradation can significantly reduce their availability (Bradai et al., 2015a). The fruiting bodies, known as truffles, typically emerge during the rainy season, which typically spans from January or February to April or May, depending on the specific geographical region (Thomas et al., 2019). Additionally, human activities such as agriculture, urbanisation, and overharvesting can impact truffle habitats, further affecting their distribution and abundance (Samils et al., 2008).

Desert truffles are highly prized in regions such as the Mediterranean basin, the Middle East, and the Gulf areas for their culinary and nutritional value and medicinal benefits (Owaid, 2018; Morte et al., 2021; Slama et al., 2010). Studies have shown desert truffles to contain protein, fats, fibre, carbohydrates, and essential vitamins and minerals (Shavit, 2014; Farag et al., 2021). Truffles are esteemed for their unique flavour and nutritional value, making them a sought-after ingredient in numerous culinary dishes (Shavit, 2014; Lee et al., 2020; Allen and Bennett, 2021). In many regions, they are considered gourmet food featured in stews, salads, soups, and rice dishes (Shavit, 2014). Beyond their gastronomic appeal, truffles have medicinal uses and are believed to possess properties beneficial for treating several ailments, including eye conditions (Patel et al., 2017; Lee et al., 2020). Medicinally, they exhibit antibiotic, antioxidant, anticancer, and immunomodulatory properties (Owaid, 2018).

The trade of truffles and desert truffles contributes significantly or could contribute to local economies, providing income for many rural families who engage in their collection and sale, for instance, in North Africa (Volpato et al., 2013) and Italy (Pieroni, 2016; Calvo et al., 2020). Commercially, they fetch high prices in local and international markets, enhancing the livelihoods of those involved in their collection and trade (Samils et al., 2008; Calvo et al., 2020; Morte et al., 2021). Culturally, truffle gathering is a practice that fosters community bonds and preserves traditional knowledge passed down through generations (Shavit, 2014; Calvo et al., 2022). This multifaceted role underscores the truffle's importance in the communities' daily lives and cultural heritage. Embedded within local cultures and livelihoods, the act of truffle hunting serves as more than just a means of sustenance; it reflects longstanding traditions and connections to the land, enriching the socio-economic fabric of these communities (Shavit, 2014; Savelli et al., 2019). Until now, desert truffles have primarily been harvested from their natural habitats by desert residents (Morte et al., 2021). Historically, desert truffle cultivation has not received significant attention in agricultural research and development. Nonetheless, the rising demand for novel culinary ingredients has fueled interest in desert truffles (Shavit, 2014; Lee et al., 2020). Additionally, the escalating effects of global warming and the pressing need for new crops suited to arid environments have spurred increased efforts toward domestication (Morte et al., 2021).

The relationship between truffles and human communities is a prime example of ethnoscience and human ecology (Bates and Tucker, 2010; Savelli et al., 2019). Ethnoscience explores how different cultures understand and interact with their natural environment, while human ecology examines the dynamic interplay between humans and their ecosystems (Volpato et al., 2013; Shavit, 2014). In each region, traditional knowledge and practices related to truffle gathering demonstrate the intricate connections between cultural heritage and ecological adaptation (Pieroni, 2016; Calvo et al., 2022). These practices are influenced by geographical location, environmental conditions, and socioeconomic factors, illustrating the diversity of human ecological interactions with truffle habitats (Samils et al., 2008; Turgeman et al., 2011).

The objectives of the study were, therefore, a) to document the local ecological knowledge associated with desert truffle hunting among three different socio-cultural groups - Arabs, Kurds, and Sardinians, examining the socio-economic, cultural, and environmental dimensions of this activity; b) to document and compare the perceived threats to desert truffle hunting among the studied communities. By analysing these aspects, the study aims to contribute to a deeper understanding of human ecological perspectives and the role of traditional knowledge in sustaining truffle populations and the communities that depend on them. Through this comparative analysis, the research highlights the significance of preserving these practices in the face of environmental and socio-economic changes. Each of the selected case studies has a rich history of truffle hunting, shaped by specific economic, social, and environmental conditions (Shavit, 2014; Sulaiman et al., 2024; Allen and Bennett, 2021).

2. Methods

2.1. Study area

The collection sites across Central and Easter Mediterranean were strategically selected for their ecological diversity and local culinary traditions, encompassing regions across Iraq, Eastern Turkey, Syria, and Sardinia, Italy, ensuring relevance to truffle habitats and harvesting practices. (Fig. 1).

In Iraq, distinct districts such as Garmyan, Chamchamal, Altun Kopri, Samawah Desert, and Anbar inhabited by Kurdish and Arabic communities, show truffle hunting traditions shaped by their geographical and cultural surroundings (Forti et al., 2021). These regions range from semi-arid environments to extensive desert landscapes, each contributing to the country's rich tapestry of truffle-gathering practices (Al-Ansari, 2021; Forti et al., 2021). The climate in these areas is characterized by low annual precipitation (200–300 mm) and high temperatures during the summer, creating ideal conditions for desert truffles to thrive in sandy and calcareous soils.

The southeastern region of Southern Turkey, including cities like Urfa, Mardin, Batman, and Diyarbakır, boasts a diverse landscape that transitions from semi-arid to fertile agricultural areas. The climate here is characterized by hot, dry summers and cooler, wetter winters, with annual rainfall ranging from 500 to 600 mm (Steidinger et al., 2022). These conditions, combined with the region's soil types, provide an ideal environment for truffle growth. Truffle hunting is deeply rooted in the local culture, and knowledge of truffle gathering techniques has been passed down through generations in these communities.

Syria's landscape is marked by its dramatic contrasts, ranging from fertile plains and high mountains to vast deserts. The semi-arid and arid zones, particularly the Syrian Desert (desert, semi-desert and steppe), cover about 55 % of the country's total area and are suitable for desert truffles, which thrive in sandy and calcareous soils (the rangelands of the Syrian Arab Republic, 2021). The altitudes in truffle-producing areas vary, typically ranging from low-lying plains to elevations of around 500 to 1000 m above sea level. The truffle-producing areas experience low annual rainfall (100–200 mm) and are characterized by hot summers and mild winters, ideal for desert truffle growth (the rangelands of the

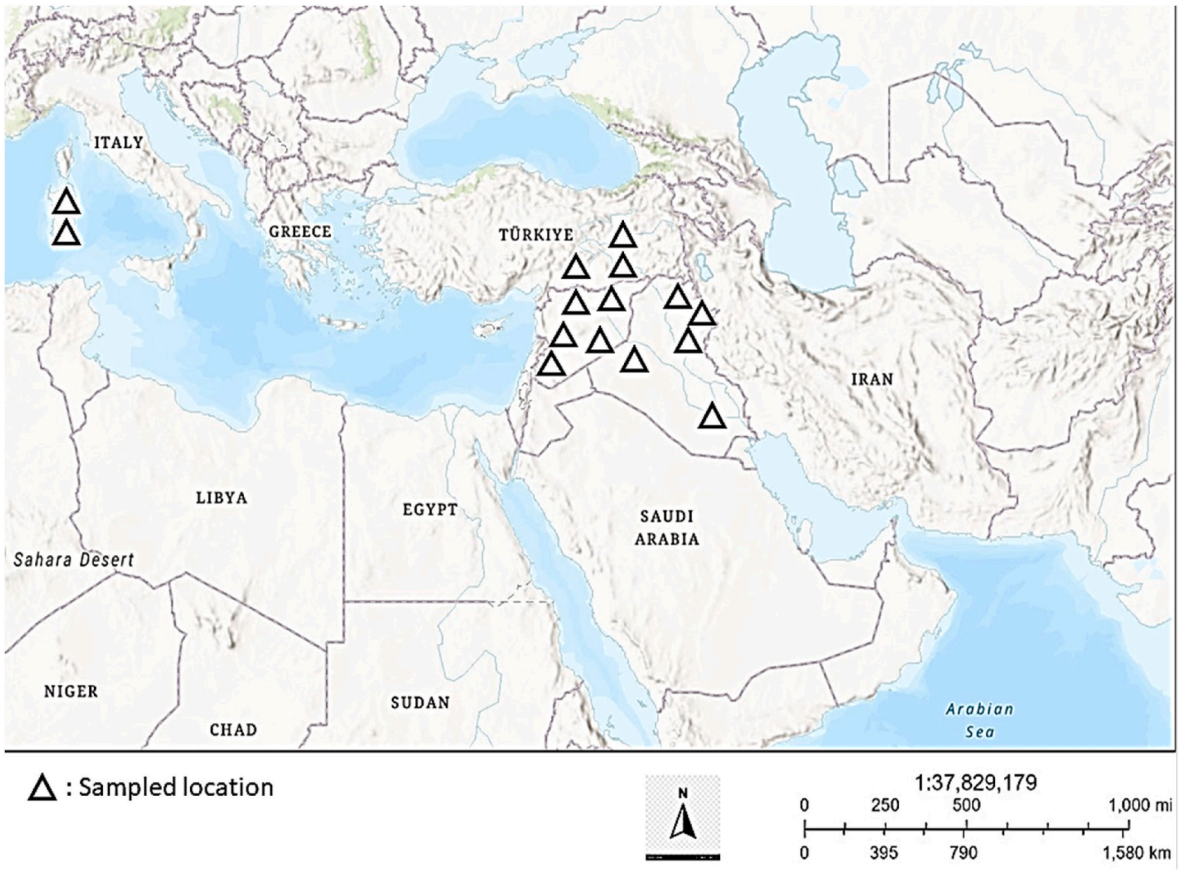

Fig. 1. A map showing the study area locations in Iraq, Turkey, Syria, and Sardinia (Italy). The map was adapted from ArcGIS software.

Syrian Arab Republic, 2021). Prominent areas like Homs, Hama, Aleppo, Rural Damascus, Deir el-Zor, Raqqa, Al-Hasakah, Sweida, and the Syrian Badia offer diverse habitats for truffle growth and hunting (Faour et al., 2010).

Sardinia, an island region of Italy, has a topography that includes highlands, plateaus, and low plains, supporting rich biodiversity. The climate of Sardinia, with annual rainfall ranging between 500 and 600 mm and mild winters, is conducive to truffle growth. In the municipalities of Oristano, Terralba, Santa Giusta, and Portoscuso, truffle hunting is a century-old tradition, passed down through generations. The island's varied ecosystems, particularly its limestone-rich soils, contribute to the presence of a diverse range of truffles, making it a significant region for the study of truffle diversity and hunting practices.

2.2. Data collection

In our study, we employed a multistage random selection approach to choose zones and places within the designated study areas. From the study area, we selected twenty-one places, each carefully chosen to represent the diversity of ecological zones and cultural contexts. These included various locations such as Garmyan, Chamchamal, Altun Kopri, Samawah Desert, and Anbarin (Iraq, including the Kurdistan Region); Homs, Hama, Aleppo, Deir el-Zor, Raqqa, Al-Hasakah, Sweida, and Syrian Badia in Syria; Oristano, Terralba, Santa Giusta, and Portoscuso in Sardinia; Mardin, Urfa, Batman and Diyarbakır cities in Turkey (Fig. 1). Field trips to each area took place between 2022 and 2024 to ensure comprehensive data collection.

Interviews conducted during these field trips adhered strictly to the codes of ethics outlined by the International Society of Ethnobiology (2006), and the American Anthropological Association. We interviewed 46 desert truffle hunters in our study, representing a diverse range of ethnicities, occupations, and demographic characteristics.

Questions were asked in the participants' local languages, including Arabic (in Syria and Iraq), Italian (in Sardinia), and Turkish (in Turkey), to ensure clear communication and accurate information gathering. Participants were selected based on their knowledge and experience with desert truffles, including truffle hunters, local residents, and culinary experts. This selection process aimed to capture diverse perspectives and expertise, ensuring a comprehensive understanding of the cultural, ecological, and socio-economic aspects of desert truffles across different regions.

2.3. Data analysis

Gathered data were translated into English and organized in an Excel table according to each interviewee and question of the interview. The data analysis was conducted using SAS 9.4 software (SAS Institute Inc., Cary, NC, USA), employing descriptive statistics such as means, medians, and other relevant measures to characterise the dataset. Additionally, we employed thematic analysis to extract rich insights from the interviews, observations, and field notes. This qualitative technique helped identify recurring patterns, themes, and cultural nuances related to desert truffle gathering. We systematically coded the data, allowing us to categorize key concepts and explore the socio-cultural significance of the practices across different regions. Text mining tools provided by SAS were utilized to analyse unstructured text data to uncover underlying meanings and extract valuable insights into the practices and perceptions of truffle hunters in each region.

Furthermore, a comparative analysis approach was adopted to examine similarities and differences across the studied populations of Arabs, Turks, and Sardinians. This involved systematically comparing and contrasting the gathered data to identify commonalities and

distinctions in truffle-gathering techniques, socio-cultural dynamics, and perceptions among the three groups. To explore the causal relationships between various threats to desert truffles, a path analysis was conducted. The model included several variables such as habitat destruction, climate change, overharvesting, and conflict-induced land degradation, in order to determine how these factors interact and affect desert truffle production. Path analysis allowed us to quantify the direct and indirect effects of these threats, providing insight into the primary causal chains affecting the sustainability of desert truffles across different regions. This analysis identified key pathways through which these threats contribute to truffle decline and assessed the strength and significance of these relationships. Principal Component Analysis (PCA) was used to analyse the most important components to illustrate the significant threats to desert truffles across the study zones, highlighting the principal components contributing to the variability in threat perception.

3. Results

3.1. Identification of desert Truffle collected across Iraq, Turkey, Syria, and Sardinia

We inventoried the desert truffle species collected from the various sites of this study. The identification process includes species names, collection sites, associated ecological cues, culinary traditions, morphological characteristics, and molecular/taxonomic data. Desert truffles were classified based on distinct morphological traits such as shape, color, size, texture, and surface characteristics. These species are also categorized based on ecological preferences and culinary uses in regional dishes (Table 1). The classification follows morphological guidelines outlined by (Kamle et al., 2017; Díez et al., 2002).

3.2. Demographic and occupational diversity of desert Truffle hunters

Sampling reflected diverse demographics in Iraq and Eastern Turkey: 66.67 % of respondents were male, while 33.33 % were female. Geographically, participants were from regions including Garmyan, Chamchamal, Altun Kopri, Samawah Desert, Anbar, having the highest representation (33.33 %). Occupationally, the sample included homemakers, sellers, chefs, retirees, and others, highlighting varied socio-economic backgrounds. Notably, in the Kurdistan region of Iraq, both the mean and median age are calculated to be 44.5 years, indicating a more balanced distribution across age groups compared to Sardinia.

Data collected from various regions in Syria provided insights into desert truffle gatherers' geographical distribution. This geographical spread enabled a comprehensive analysis of truffle gathering practices across different landscapes and communities within Syria. Sampling regions have witnessed an unstable security situation over the past thirteen years due to the current conflict in Syria. These areas experienced food insecurity status, where wild foraging was used as a coping strategy (Sulaiman et al., 2023).

Sampling population (Table 2) from Sardinia comprised 15 participants, with 73.33 % male (11 participants) and 26.67 % female (four participants) representation. Occupationally, the majority were pensioners (33.33 %), followed by employees and workers (26.67 %), teachers (13.33 %), engineers, and cooks (6.67 %). Age distribution varied, with the highest percentage in the 61–70 age group (46.67 %), followed by 71+ (20 %), 51–60 (26.67 %), and 35–40 (6.67 %). In Sardinia, where detailed age data was provided, the mean age is approximately 57 years, with a median age of 65.5 years. This suggests a prevalence of older individuals engaging in truffle hunting in this region. Geographically, participants were mainly from Oristano (53.33 %), followed by Terralba and Santa Giusta (both 20 %), and Portoscuso (6.67 %). Most reported that desert truffle gathering is still in use (86.67 %), with relatives being the primary teaching source (86.67 %).

3.3. Comparative overview

Table (3) illustrates those hunters in Iraq a diverse group, including rural residents, herbalists, and individuals seeking supplemental income. Truffles grow in specific seasons: post-thundery rains in Iraq, rainy days of March and April in Eastern Turkey, late winter during the 70-day "*Al-Wasem*" period in Syria, and following the rainy season in Sardinia. Hunters learn techniques and collection spots through traditional methods, family transmission, and environmental cues, with tools varying from sticks and small shovels to pointed tools. The outcomes of gathering truffles include income generation, culinary uses, and traditional medicine, with market prices fluctuating based on various factors. Traditional consumption involves diverse culinary methods, such as frying, roasting, stews, salads, soups, and rice dishes, with preservation methods ensuring year-round availability. The search techniques often involve probing the ground with sticks or relying on environmental cues. While associated flora are specified for Syria (Syrian sun-rose plant), they are not mentioned for the other regions. Truffle hunting is commercially significant in all areas, with changes in abundance influenced by environmental factors, particularly rainfall patterns and climate change.

3.4. The desert Truffle hunters

Truffle hunting attracts individuals from diverse backgrounds across regions where these fungi thrive, reflecting the cultural and socio-economic diversity of these areas. In Iraq, for instance, truffle hunters comprise a varied demographic, including rural dwellers, herbalists, and those seeking supplementary income, spanning different ages and professions. Similarly, Eastern Turkey boasts a heterogeneous truffle hunting community, encompassing shepherds, local residents, and professionals like doctors, lawyers, and civil servants, indicating widespread cultural appreciation and economic importance. Syrian truffle hunters, predominantly from rural locales like Homs and Raqqa, exhibit a similar diversity in age and occupation, often inheriting their expertise through familial traditions. In Sardinia, truffle hunters primarily consist of men, while women may play supporting roles in activities like processing or selling truffles, predominantly hailing from coastal areas such

Table 1
Identification and ecological context of some desert truffle species collected across the study sites.

Species Name	Collection Site	Ecological Cues	Culinary Traditions	Morphological Characteristics
Terfezia boudieri Chatin	Garmyan, Iraq	Various pH calcareous sandy soils	Used in traditional Kurdish dishes (cooked)	Brown to yellow color, globose shape, 3–6 cm in diameter, rough texture
Terfezia boudieri Chatin	Mardin, Turkey	Found at higher altitudes, prefers sandy soils	Featured in local Turkish cuisine (cooked)	Pale to dark brown, irregular shape, 2–5 cm in diameter, smooth texture
Terfezia claveryi Chatin	Aleppo, Syria	Thrives in semi-arid environments	Commonly used in Syrian stews	Light brown to cream color, elongated shape, 4–7 cm in diameter, slightly wrinkled
Terfezia arenaria (Moris) Trappe,	Oristano, Sardinia	Prefers limestone soils and moderate rainfall	Integral to Sardinian culinary traditions (cooked)	Yellowish-brown, rounded shape, 3–8 cm in diameter, fibrous texture
Terfezia sp.	Samawah, Iraq	Grows in sandy loam, thrives in dry conditions	Used in traditional cooked dishes and also in salads	Dark brown, flat shape, 3–4 cm in diameter, velvety texture

Table 2
Demographic data of the study participants.

Item	Iraq	Turkey	Syria	Sardinia (Italy)
Gender	Male: 7 (66.67 %), Female: 3 (33.33 %)	Male: 7 (77.77 %), Female: 2 (22.22 %)	Male: 18 (75 %), Female: 6 (25 %)	Male: 11 (73.33 %), Female: 4 (26.67 %)
Occupation	Herbalist: 1 (11.11 %), Homemaker: 3 (33.33 %), Driver: 1 (11.11 %), Retired: 1 (11.11 %), Seller: 2 (22.22 %), Chef: 1 (11.11 %), Shopkeeper: 1 (11.11 %)	Seller: 3 (33.33 %), Herbalist: 2 (22.22 %), Doctor: 1 (11.11 %), Civil servant: 2 (22.22 %), Lawyer: 1 (11.11 %)	Herbalist: 4 (16.66 %), Homemaker: 4 (16.66 %), traditional gatherer 12 (50 %), Seller: 4 (16.66 %),	Pensioner: 5 (33.33 %), Engineer: 1 (6.67 %), Cook: 1 (6.67 %), Teacher: 2 (13.33 %), Employee: 4 (26.67 %), Worker: 2 (13.33 %)
Age group	20-29: 1 (11.11 %), 30–39: 1 (11.11 %), 40–49: 2 (22.22 %), 50–59: 3 (33.33 %), 60–69: 2 (22.22 %)	30-45: 4 (44.44 %), 50–56: 3 (33.33 %), 60–72: 2 (22.22 %)	<30: 10 (41.66 %), 30-30-40: 6 (25 %), >40: 8 (33.33 %),	35-40: 1 (6.67 %), 51–60: 4 (26.67 %), 61–70: 7 (46.67 %), 71+: 3 (20 %)
Still actively practising desert truffle hunting	Not specified	Yes: 8 (88.88 %), No: 1(11.11 %)	Yes: 20 (83.33 %), No: 4 (16.66 %)	Yes: 13 (86.67 %), No: 2 (13.33 %)
Teaching Source	Not specified	Relatives: 7 (77.77 %), Acquaintances: 2 (22.22 %)	Relatives: 16 (66.66 %), Acquaintances: 8 (33.33 %)	Relatives: 13 (86.67 %), Acquaintances: 2 (13.33 %)
Place	Garmyan: 1 (11.11 %), Samawah desert: 1 (11.11 %), Anbar: 2 (22.22 %), Samawah: 3 (33.33 %), Chamchamal: 1 (11.11 %), Altun kopri: 1 (11.11 %)	Urfa: 3 (33.33 %), Mardin: 3 (33.33 %), Batman: 2 (22.22 %), Diyarbakır: 1 (11.11 %)	Homs: 2, Hama: 4, Aleppo:4, Deir ez-Zor: 2, Raqqa: 4, Al-Hasakah: 1, Sweida: 4, Syrian Badia: 3	Oristano: 8 (53.33 %), Terralba: 3 (20 %), Santa Giusta: 3 (20 %), Portoscuso: 1 (6.67 %)
Purpose of Collection	Traditional medicine: 4 (44.44 %), Livelihood: 2 (22.22 %), Cooking: 3 (33.33 %)	Livelihood: 4 (44.44 %), Cooking: 5 (55.55 %)	Traditional medicine: 3 (12.5 %), Livelihood: 20 (83.33 %), Cooking: 1 (4.16 %)	Not specified

as Oristano and Sulcis Iglesiente. Unlike their counterparts in Syria and Iraq, these hunters' main occupations are not directly related to botany or mycology. Instead, they often work in professions such as fishing, agriculture, or tourism, reflecting the diverse economic landscape of the region. Despite these nuances, truffle hunting in Sardinia remains deeply entrenched in local culture, serving as both a traditional pastime and an economic pursuit for coastal communities.

3.5. How is the desert Truffle hunting practiced?

Desert truffle hunting varies significantly across the studied regions and is influenced by local environmental conditions and traditional practices.

In Iraq (including Kurdistan region), the growth of truffles is often associated with the spring season, following thunderstorms, leading to their historical moniker as the "thunder plant" among Arab communities. Typically situated 5–15 cm below ground, their emergence is indicated by surface cracks and the gathering of flying insects. According to the interviewees, truffle formation is believed to occur in response to lightning during rain showers. Local beliefs suggest that lightning discharges may influence soil chemistry, potentially affecting microbial activity and nutrient availability in ways that could promote fungal growth. However, there is currently no established scientific evidence supporting this claim. Further research is needed to explore the potential effects of lightning on soil composition and its role in truffle formation. Furthermore, environmental factors such as soil temperature and moisture are known to play significant roles in fungal growth, as highlighted by Pietikäinen et al. (2005), who found that such factors can enhance fungal activity in soil environments. Truffles exhibit diverse characteristics, with variations in colour, taste, smell, size, and shape, and their weight ranges from (30-300) grams per seed, influenced by factors such as soil type, hardness, and the surrounding tree species. Some varieties feature a dark red hue with a hard shell, while others boast a distinctive white colour and aroma. Each type offers a unique sensory experience, reflecting the diverse ecological contexts in which they thrive. In Iraq, truffle hunters use various tools, such as sticks with pins and small spade-shaped shovels, to probe the ground in search of these delicacies. In the deserts near Basra, a successful season can see a group of five hunters collecting up to 15 kg of truffles. Once located, some hunters prefer to take a hands-on approach, delicately cleaning the truffles to remove any traces of soil.

In Eastern Turkey, this mushroom finds its habitat in dry pasturelands situated in plains, particularly favouring southern slopes. Its development coincides with the rainy days typically observed during March and April. Recognisable by the subtle swelling of the ground where it emerges or by the appearance of surface cracks, this mushroom holds significance in local folklore and is believed to materialise following lightning strikes. The collection technique involves cleaning the soil around the truffle and using a pointed tool, such as a stick, screwdriver, or knife, to dig until reaching the mushroom's base. An example from Diyarbakir shows that even professionals like doctors and engineers join the hunt during weekends, blending traditional methods with modern tools. This method is passed down through local communities and incorporates traditional knowledge and practical tools available to the hunters.

Syria boasts a rich diversity of wild mushrooms, with one of the most prized varieties being the truffle. Known locally as "*Fqa'a*" or "*Kama'a*" these desert truffles are esteemed for their nutritional value and typically appear in late winter, buried approximately 5–15 cm beneath the earth's surface. The emergence of these mushrooms coincides with the 70-day period known as "*Al-Wasem*" bridging the gap between the rising of the star Sirius and the onset of winter. This period, often associated with cold weather, is locally referred to as "*Awaa Al-Barad*" or the cold's howl, indicating its arrival with the cold and signaling optimal times for rainfall. This season typically spans from mid-October to mid-December. Local lore suggests that the appearance of these mushrooms is often accompanied by lightning and thunder, which elevate atmospheric nitrogen oxide levels. When combined with raindrops, these conditions create an ideal environment for truffle growth, affectionately dubbed "*Bint Al-Ra'd*" or the thunder's daughter. Truffles, as symbiotic fungi, thrive in specific host plant environments and can be found at depths ranging from two to 50 cm below the surface, often in undisturbed areas. ruffles typically boast a spherical shape with a smooth, uniform, fleshy surface, exhibiting colors ranging from white to beige to black. Their sizes vary from three to 15 cm in diameter, with weights ranging from 20 to 400 g. Common varieties include the "*Harqa*" (small, brown truffles), the "*Hooper*" (tiny black truffles with a black exterior and white interior resembling hazelnuts), and the "*Jibby*" (also black but larger). Rarer specimens include the "*Zubaidi*" (large, white truffles) and the "*Khalasi*" (smaller, reddish truffles). For many rural people residing near the Syrian Badia, truffle-producing lands are affectionately called "*Ard Al-Khair*" or the land of goodness. These areas provide a seasonal bounty without requiring land ownership or cultivation. In Syria, Truffles, also known as "*Kama'a*", "*Tarfas*", and "*Jmaya*" are frequently found in

Table 3
Comparison between the sampled areas and summarised narrative answers.

Main interview questions	Main (summarised) answers			
	Iraq (10 participants)	Turkey (9 participants)	Syria (24 participants)	Sardinia (Italy, 15 participants)
Who are the desert truffle hunters?	Diverse groups, including rural residents, herbalists, and individuals seeking supplemental income, with varying ages and occupations.	Various demographics include shepherds, locals with limited land, and professionals such as doctors, lawyers, engineers, civil servants, and tradespeople.	They are primarily rural inhabitants with diverse age ranges and occupations, including those from Homs, Hama, Aleppo, Deir el-Zor, and Raqqa.	Men aged between 35 and 75 from the coastal area of Oristano and Sulcis Iglesiente, Sardinia, with occupations not directly related to botany or mycology.
In which season do desert truffles grow?	Truffles in Iraq typically appear following thundery rains in desert and sandy environments. Collection techniques vary, with hunters relying on traditional knowledge and environmental cues to locate truffle-rich areas.	Desert truffles in eastern Turkey thrive in dry pasture lands, predominantly on southern slopes, developing during the rainy days of March and April.	Truffles appear in late winter, buried about 5–15 cm beneath the ground's surface. They emerge during the 70-day period known as "*Al-Wasem*" which bridges the gap between the rising of the star Sirius and the onset of winter.	Sardinia truffles are typically abundant in desert regions and sandy environments following the rainy season when the soil becomes moist. They grow in clusters of 10–20 pieces in a single location.
How do desert truffle gatherers learn the technique and spots of collection?	Truffle hunters in Iraq use sticks with pins and small spade-shaped shovels to probe the ground for truffles. Some prefer to extract truffles by hand, delicately cleaning them from any traces of earth.	The technique of truffle collection involves cleaning the soil around the truffle and digging with a pointed tool, such as a stick, screwdriver, or knife, until reaching the mushroom's base.	Truffle hunters acquire collection techniques from one another and transmit them across generations. The presence of the Syrian sun-rose plant (*Fumana arabica) often* indicates the presence of truffles underground.	Truffle hunting skills are often passed down within families, with children accompanying elder relatives to learn the art of truffle gathering.
What are the outcomes of the gathering?	Truffle harvesting yields various outcomes, including income generation, traditional medicine production, and culinary uses.	Desert truffles are sold in public markets in regions where they grow extensively despite the challenges posed by climate change. As of April 2024, the market price per kilogram is approximately 1000 Turkish Lira, equivalent to 30 dollars.	Truffles are harvested for both local consumption and commercial purposes. Market prices fluctuate significantly over time, influenced by accessibility, demand, and currency depreciation.	Truffles are harvested and sold in markets, with prices influenced by factors such as availability, demand, and quality.
How are truffles traditionally consumed?	Truffles are prized for their culinary versatility. Traditional recipes feature truffle-based dishes enjoyed by families and served in restaurants.	Desert truffles are cleaned of soil and prepared in various ways for home consumption, including frying with eggs, roasting directly, or freezing for later use.	Truffles are consumed in various culinary dishes, including stews, salads, soups, and rice dishes. Traditional preservation methods ensure year-round availability and medicinal use in treating eye ailments.	Truffles are cooked in various dishes such as stews, salads, soups, and rice dishes and are also boiled and preserved for consumption outside of their harvesting seasons.
How do truffle hunters search for desert truffles?	Use sticks with pins and small shovels to probe the ground	Rely on environmental cues, use pointed tools for extraction	Rely on environmental cues such as cracks in the ground and the presence of specific flora	Use sticks with sharp tips, sometimes without metal protrusions, to probe the ground
Which is the flora associated with desert truffles?	Not specified	Not specified	The presence of the Syrian sun-rose plant (*Fumana arabica)* often indicates truffle-rich areas	The presence of the plant often indicates truffle-rich areas
Are desert truffles hunted also for commercial purposes?	Yes, it is used for income generation and culinary purposes	Yes, it is sold in public markets for local and commercial use	Yes, it is harvested for both local consumption and commercial purposes	Yes, sold in markets
Abundance and its changes over the past few decades	Yes, it is influenced by environmental factors such as rainfall patterns	Not specified	Yes, it is influenced by climate change and environmental factors	Not specified

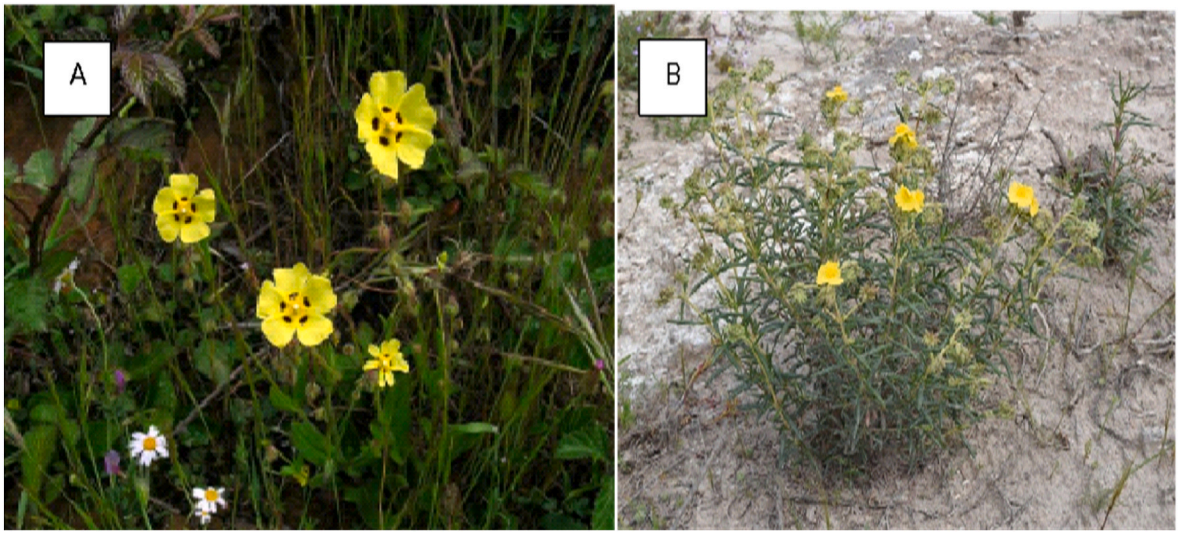

Fig. 2. Indicators of desert truffle habitats - (A) *Tuberaria guttata* (Sardinia), (B) *Fumana arabica* (Syria).

desert regions and sandy environments after periods of rainfall when the soil becomes damp. They typically grow in clusters of 10–20 pieces, resembling potatoes in shape but varying in colour and scent. Truffle hunters often identify their presence by observing cracks in the ground surrounding their growth sites, hovering insects, or the existence of the Syrian sun-rose plant, also known as "*Ruqroq*" or "*Raqqa*". The rockrose plant, particularly the Syrian rockrose (*Fumana arabica*), shares a symbiotic relationship with truffles, indicating that truffles are likely to be found where rockrose thrives. Rockrose plants prefer rocky and gypsum-rich soils. The rockrose genus *Fumana*, which belongs to the Cistaceae family, includes 73 accepted species. One of these species is *Fumana arabica*, commonly known as the Syrian rockrose or "Syrian Sun-rose" (*Fumana arabica*) (Fig. 2).This perennial evergreen shrub, characterised by its dwarf size and firmness, thrives in rocky shrubs and open forests, deriving its name from its ability to grow among rocks, with leaves resembling lavender plants. Truffle gatherers often learn

Fig. 3. Different desert truffle-based traditional dishes in the study areas. A,B,C (Iraq); D (Eastern Turkey); D,E,F,G,H,I,J,K,L (Syria); M,N,O (the Sinis area, Oristano, and Sulcis).

collection techniques from one another, passing them down through generations and sharing news of notable discoveries, especially of exceptional truffles.

In Sardinia, truffles are most abundant in sandy environments after the rainy season when the soil becomes moist. They grow in clusters of 10–20 pieces in a single location, allowing hunters to harvest multiple truffles from one spot. The timing and location of truffle emergence are closely tied to the region's specific environmental conditions. Truffle hunting in the Oristano region of Sardinia primarily involves using a stick with a spike and a small pick-like blade known as "*S'Arrodeddu*". However, different names are used for this tool in other parts of Sardinia, such as "*Bastoi*", "*Puncioi*", and "*U Fustigheddu*". In the Sulcis Iglesiente area, where the practice is carried out by a few remaining families, hunters typically use a 1-m-long stick made of juniper wood to delicately extract truffles by hand. This traditional technique, "*A sperciu*", involves visually probing the terrain for sand cracks created by developing truffles beneath the surface.

Across all regions, the transmission of truffle hunting knowledge is a crucial element in the sustainability of the practice. Whether through family traditions or communal learning, the methods are tailored to the specific environmental conditions and cultural contexts of each region. This shared yet regionally distinct knowledge highlights the importance of cultural heritage in the ecological practice of truffle hunting.

3.6. Traditional consumption of desert truffles

The culinary traditions associated with desert truffles are rich and varied, reflecting the diverse cultures and local practices of Iraq, Eastern Turkey, Syria, and Sardinia.

In Iraq, truffles are prized for their culinary versatility, with traditional recipes featuring truffle-based dishes enjoyed by families and served in restaurants with nearly 75 % of respondents mentioning that truffles are incorporated into various dishes such as meat stews, soups, and rice dishes., enhancing the flavours with their unique aroma. For instance, in Samawah, some restaurants dedicate a specific day each week to serving truffles, a delicacy locals enjoy. Truffles are prepared in various ways, with frying or grilling being common methods. However, the preferred dish among customers is truffle rice. Abu Mohamad, a local resident, mentioned the popularity of this tradition.

An easy recipe for preparing truffles, known locally as "*Faqaa*", involves simple ingredients and steps. Begin by frying sliced onions in oil until golden brown. Then, add chopped tomatoes, tomato paste, turmeric, grated ginger, spices, and salt to the pan. Fry the mixture until it becomes aromatic. Next, add cleaned and chopped truffles to the pan and stir-fry them with the other ingredients. Pour in enough water to create a thick sauce, then reduce the heat and let the truffles simmer for about 15 min until cooked and most of the water has evaporated. Serve the truffles hot, and enjoy the flavours of this traditional dish. In the Kurdistan Region of Iraq, truffles are also used in traditional medicine and are believed to have health benefits for eye conditions (Fig. 3A and B,C).

In Eastern Turkey, desert truffles are cleaned of any soil and prepared in various ways for home consumptionwith 70 % of respondents noting that they fry truffles with eggs or roast them directly over an open flame. or freezing them for later use. For instance, a popular method involves chopping the truffles and lightly frying them before adding bulgur and water to prepare a savory pilav. Another common preparation is to place the truffles on skewers and roast them over an open flame, a method that brings out their natural flavors. Additionally, 40 % of respondents reported using truffles in kebabs, chopped into small pieces and cooked with meat or incorporated into a rich, flavorful broth (Fig. 3, D).

In Syria, truffles offer a versatile range of culinary possibilities with 80 % of interviewees indicating that they prepare truffles by boiling them with rice and lamb for a flavorful dish. 65 %, prefer grilling truffles with meat for a unique flavor, while 55 % enjoy them in stews or salads especially in Aleppo. Another beloved dish in the region is "*Mahshi Al-Kamaia*", where truffles are stuffed with rice and served alongside stuffed zucchini and eggplant. For storage, truffles are cleaned thoroughly by washing them multiple times and removing any soil residue. Grooves on the surface are meticulously cleaned with a knife before boiling them in salted water for approximately 10 min. After boiling, the truffle pieces are stored in plastic bags in the freezer. The remaining water, filtered and reduced to one-third of its original volume, is also stored for later use, preferably with the addition of lamb fat during cooking. The firmer variety of truffles is preferred for cooking purposes (Fig. 3D and E,F,G,H,I,J,K,L).

In Sardinia (Italy), desert truffles are typically sautéed and served with lamb stew or potatoes, with 50 % of respondents mentioning these traditional recipes. The truffles in Sardinia are noted for having a milder aroma compared to other regions. In Sulcis Iglesiente, few hunters remain. In Portoscuso, where we conducted an interview, only four families preserved their knowledge and tradition of truffle hunting and culinary transformation. A traditional recipe in this area involves sautéing truffles and pairing them with lamb stew. These truffles, unlike "classic" truffles, have a less intense aroma and are therefore cooked rather than consumed raw, often served sautéed with pasta. In the Oristano area, truffle hunting is slightly more widespread due to the larger search territory and higher population density. However, the practice is gradually disappearing, leading to a decline in knowledge of culinary transformation. Traditionally, truffles in this area are also sautéed and served with lamb or potatoes. Each interviewee has their interpretation of a "traditional recipe", with variations in ingredients such as pairing with pasta or other wild herbs or cooking with lamb stew or peas for a vegetarian option. In Oristano, a popular dish is "*Tuvare de arena alla Vernaccia*", where cleaned and sliced truffles are sautéed and deglazed with Vernaccia di Oristano wine. Eggs are added, and the dish is cooked until the alcohol evaporates, resulting in a soft red finish. This culinary practice is common among all informants. Some recipes resemble those from other countries, such as sautéing cubed truffles and serving them with scrambled eggs, reminiscent of street food in Baghdad. Another recipe pairs truffles with eggs and asparagus, a typical Spanish preparation, suggesting possible exchanges of ideas and knowledge between countries in the pastoral simply influenced by geographic proximity (Fig. 3M and N,O).

3.7. The economic importance of desert Truffle gathering across different zones

In Iraq, the desert truffle market exhibits variability in prices based on factors such as annual fluctuations and truffle types. Prices have surged this year due to scarcity, with 1 kg ranging between 70,000 and 100,000 Iraqi dinars (approximately $48 to $68) at the beginning of the season, dropping to 10,000 to 15,000 dinars (approximately $6 to $10) later based on market demand. Truffles from Chamchamal, Kurdistan Region of Iraq, particularly renowned for their size and quality, command higher prices, reaching up to 100,000 Iraqi dinars per kilogram. Additionally, truffles from other regions, like Baghdad, are also sold in the market, further diversifying the offerings and price ranges.

In Eastern Turkey, desert truffles are sold in public markets in regions where they grow extensively, despite the challenges posed by climate change. As of April 2024, the market price per kilogram is approximately 1000 Turkish Lira (equivalent to 30 USD). In the city of Diyarbakir, for instance, local markets bustle with activity during truffle season, with traders and consumers negotiating prices. The revenue from truffle sales is a vital part of the livelihood for many, including shepherds and other rural residents.

In Syria, the desert truffle market has undergone significant changes over the years. Before 2011, truffles were a staple meal for many families, with prices ranging from 500 to 1000 Syrian pounds per kilogram (around 10 to 20 USD). However, by 2024, prices have surged dramatically, ranging from 75,000 to 400,000 Syrian pounds per kilogram (5–33 USD), primarily due to the risks associated with collection

and the depreciation of the local currency against the US dollar. As a result, domestic consumption has dwindled, leading to increased exports to neighboring markets. Truffles are harvested in rural areas and sold in major cities like Damascus, Aleppo, Hama, and Homs, contributing to the economic dynamics of both rural and urban regions. There is a notable security concern associated with desert truffle hunting in the Syrian case due to the current war in the country. Several media reports showed the significant threat of mines in the post-conflict zones for desert truffle hunters, in addition to the frequent attacks by terrorist groups on hunters particularly out of the Syrian governmental-controlled areas (BBC, 2024). These insights highlight the complex interplay between market dynamics, economic outcomes, and socio-political factors shaping the desert truffle industry in the Kurdistan region of Iraq, and Syria.

In Sardinia, truffles are harvested and sold in local markets, with prices influenced by factors such as availability, demand, and quality. The coastal regions of Oristano and Sulcis Iglesiente see a significant market for truffles, where high-quality specimens can command premium prices. For instance, during peak harvest times, truffles might sell for around 20 to 40 Euros per kilogram (approximately 22–44 USD). This market niche is important for local economies, especially for older men who are the primary gatherers.

Across all regions, truffle gathering s provides a significant source of income, supports local markets, and contributes to the economic resilience of rural communities.

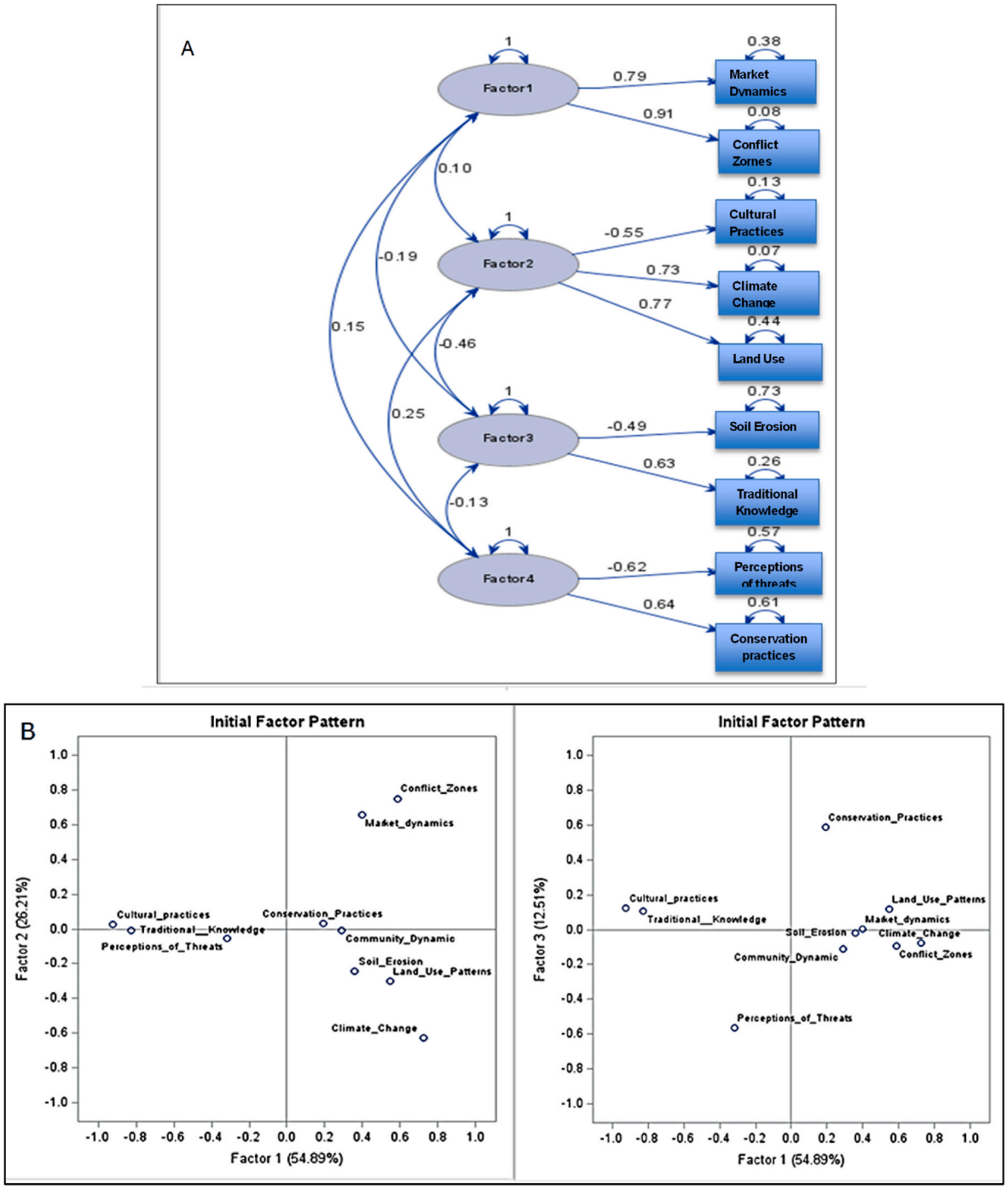

Fig. 4. Principal Component Analysis (PCA) was conducted on the major threats to desert truffles across the four study zones (Path Diagram).

3.8. Ethnoecology of desert truffles: human-nature interactions

The interview results revealed that desert truffle production has declined across the regions studied, with varying perceptions of the decline. In Iraq, approximately 75 % of interviewees noted a decrease in truffle production, mainly due to habitat destruction linked to conflicts, with climate change and overharvesting contributing to a lesser extent (35 % and 30 %, respectively). In Syria, 60 % of participants observed a decline, with 50 % attributing this to the impact of ongoing conflicts, including habitat destruction, while 30 % mentioned climate change as a contributing factor. In Turkey, 45 % of respondents reported a reduction in truffle production, primarily due to overharvesting (50 %) and climate changes (40 %). The factors driving this decline were largely consistent across the regions. Conflict-related issues, such as habitat destruction and displacement, were identified by 65 % of interviewees as key contributors to the decline. Climate change was cited by 55 % as affecting the truffle ecosystems, and overharvesting was acknowledged by 50 % of respondents, especially in areas where informal and unregulated harvesting practices are prevalent.

The PCA analysis (Fig. 4) highlights the primary factors contributing to the variability in desert truffle threat perception across the study regions. The identified factors encompass socio-economic and environmental challenges, such as market dynamics, conflict zones, cultural practices, climate change, and soil erosion.

In Figure 4B, Factor 1 explains 54.89 % of the total variance, with high loadings for market dynamics (0.79) and conflict zones (0.91) (Fig. 4A). This suggests that economic and socio-political drivers, particularly in regions like Eastern Turkey and Iraq, significantly influence threat perceptions. Conflict zones and market disruptions play a dominant role in shaping truffle conservation challenges, especially in war-affected areas like Iraq and Syria, where resource access is restricted, and local markets are destabilized.

Factor 2, which accounts for 26.21 % of the variance, is mainly characterized by climate change (0.73) and land-use patterns (0.77) (Fig. 4A). This factor emphasizes the ecological drivers impacting desert truffle habitats. For instance, land degradation, due to overgrazing or agricultural expansion in regions such as Sardinia, may exacerbate the effects of climate change, influencing how truffle hunters and communities perceive environmental threats. We observe how these factors cluster populations differently across the study areas. For instance, regions with high market instability (Eastern Turkey and Iraq) cluster together based on Factor 1, while areas with more pronounced environmental changes, like Sardinia, cluster based on Factor 2.

Factor 3 (12.51 %) reveals the importance of soil erosion (0.49) and traditional knowledge (0.63), particularly in desertification-prone areas where traditional conservation practices have helped mitigate land degradation. Lastly, Factor 4 highlights the perceptions of threats (0.62) and conservation practices (0.64) (Fig. 4A), illustrating how localized conservation efforts may reduce perceived risks in some areas.

Distinct clustering patterns are observed among the four study zones (Fig. 5): Iraq, Eastern Turkey, Syria, and Sardinia, revealing significant variation in how these regions perceive threats to desert truffles.

Iraq and Syria shows a much tighter clustering along Principal Component 2, indicating more consistent threat perceptions across regions, likely due to shared environmental pressures such as desertification and political unrest. Interestingly, the proximity of Syrian and Iraqi clusters (encircled in the plot) reflects their geographical and political similarities, as both countries face comparable environmental and socio-economic stressors.

Eastern Turkey and Sardinia display tighter, more distinct clusters along Principal Component 1, with Eastern Turkey's cluster reflecting a focus on market dynamics and conflict zones, while Sardinia's grouping suggests a greater emphasis on land-use patterns, cultural practices, and conservation efforts (Fig. 4B). These differences in clustering underline how threat perceptions are shaped by local socio-economic and ecological contexts. Iraq's dispersed pattern indicates a more fragmented view of threats, whereas Syria and Sardinia show more cohesive regional perceptions. This analysis underscores the importance of considering regional and local variations when developing conservation and management strategies for desert truffle ecosystems, as different zones prioritize different challenges.

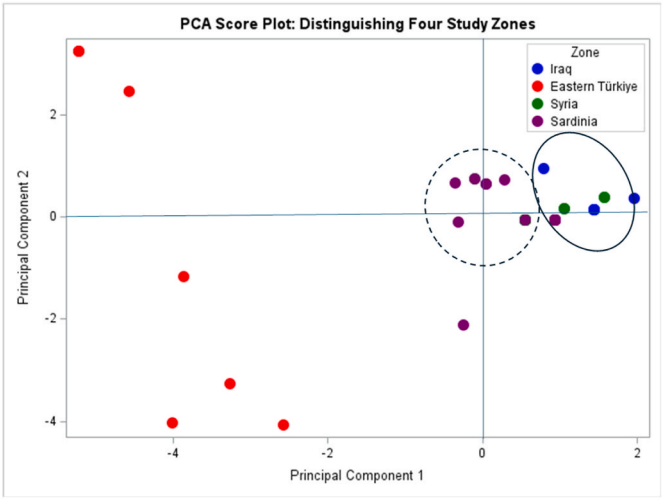

Fig. 5. PCA of the variations in perceived threats of desert truffles among the study populations.

4. Discussion

4.1. Local ecological knowledge related to desert Truffle

The results demonstrated similar patterns of profound cultural value of desert truffle hunting in all the studied communities. Hunters rely on natural indicators such as surface cracks and the presence of specific plants or insects to locate truffles. Previous studies confirm these findings. For instance (Bradai et al., 2015b; Owaid, 2018), note using natural cues such as specific vegetation and soil disturbances as indicators of truffle presence. The association of truffle growth with thunderstorms and lightning, believed to trigger truffle formation, highlights a shared belief system rooted in ecological understanding in Iraq, Turkey and Syria but not in Sardinia. This connection to weather patterns is supported by (Bradai et al., 2015a; Al-Rawi et al., 2020), who link truffle abundance to specific climatic conditions.

In the three case studies located in the Middle East, the seasonal and ecological cues used in are consistent with those in neighboring regions include North Africa (specifically, parts of Tunisia, Algeria, and Morocco) and regions in the Arabian Peninsula (such as Saudi Arabia and Jordan) (Owaid, 2018). The integration of traditional and modern methods of truffle hunting highlights the adaptability of these practices in response to changing environmental conditions. In some regions or as occasional methods, such as using trained dogs or donkeys for scent detection and manual digging with simple tools, remain widespread in the Middle East (Bates and Tucker, 2010). These techniques are deeply rooted in local knowledge and ecological observations, including seasonal and climatic cues (Owaid, 2018). However, modern approaches, such as the use of GPS mapping and digital tools to track truffle growth and habitat conditions, complement these old practices, allowing hunters to navigate more efficiently and adapt to environmental changes (Morte et al., 2021). By merging traditional knowledge with newer technologies, these methods not only ensure more sustainable truffle harvesting but also promote the resilience of hunting practices across different regions, from the Middle East to neighboring areas like North Africa and the Mediterranean (Bradai et al., 2015b).

While we could not detect gendered roles in truffle hunting in the Middle East, traditional gender-specific roles are observed within

Sardinian truffle hunting communities, with men predominantly engaging in the actual hunting process. Women play a crucial role in the post-harvest phase, which involves processing and preparing truffles for sale. This division of labour reflects historical and socio-economic adaptations within Sardinian communities, where both men and women contribute to the overall economic sustainability of truffle harvesting activities. These gendered labour characteristics aligns with findings by (Savelli et al., 2019; Calvo et al., 2020), who describe similar gender roles in other Mediterranean truffle-hunting communities. The reliance on these gender-specific roles not only underscores the cultural traditions associated with truffle hunting but also highlights the collaborative efforts necessary to sustain this practice over generations. Tregion. Socio-economic adaptation ensures that truffle hunting in Sardinia remains sustainable by balancing economic benefits with ecological preservation. Traditional knowledge of local truffle habitats is crucial, with older generations passing down sustainable harvesting practices (Bates and Tucker, 2010). Additionally, cooperative efforts and regulations help protect truffle ecosystems while allowing local communities to continue benefiting economically (Bradai et al., 2015; Morte et al., 2021). These factors work together to maintain both local livelihoods and ecological balance.

4.2. Cultural significance of desert Truffle

Desert truffle hunting transcends economic utility, deeply embedding the cultural fabric of each region studied. Truffles are integral to local cuisine in all the four study contexts. Traditional desert truffle-based dishes and hunting techniques are transmitted through familial lines, underscoring their cultural importance. This transmission ensures the preservation of knowledge and reinforces cultural identity within these communities (Owaid, 2016; Alexander, 2023; Calvo et al., 2020). Desert truffles hold medicinal practices in Iraq and Syria. Rich in crucial amino acids (Al-Rawi et al., 2020), they are valued for their nutritional benefits and are even regarded as natural aphrodisiacs. With some slight differences with our study cases, desert truffles are eaten raw or cooked (boiled, roasted over fire, or buried in hot ashes) in the African Kalahari (Trappe et al., 2008). Beyond culinary uses, truffles are considered a dietary supplement, possessing anti-inflammatory properties, and are utilized by diabetic patients. They are mentioned in various historical texts, including those by Prophet Muhammad, Ibn Sina (Avicenna), and Abu Bakr al-Razi, highlighting their significance in traditional medicine, particularly their aqueous extract used in treating eye diseases. This cultural value was also represented by the well-known Palestinian poet Mahmoud Darwish, who, in one of his poems, asked about the miracle creation of “Kama’a”.

Moreover, in Eastern Turkey, the participation of a diverse demographic, including professionals such as doctors and lawyers, indicates a broad cultural appreciation as a recreational activity. This collective effort to sustain the practice shows how truffle hunting is a communal activity that transcends social and economic boundaries, reflecting a collective cultural heritage (Shavit, 2014a; Forti et al., 2021). provide similar accounts of truffle hunting being a unifying cultural activity in the region.

4.3. Socio-economic impacts

Our findings reveal that truffle hunting may represent an additional income in all of the studied contexts, In Iraq and Eastern Turkey, income derived from desert truffle hunting supports household needs and can significantly impact the local economy during the truffle season, a pattern confirmed by (Owaid, 2018). In Syria, the socio-economic impact of truffle gathering is starkly illustrated by the drastic price increase due to conflict and currency devaluation. Despite these challenges, truffles remain a valuable export commodity, contributing to the economy despite adversity. This situation underscores the resilience of traditional practices in sustaining communities through economic turmoil, supported by the findings of (Owaid, 2018; Alexander, 2023).

4.4. Major perceived threats

The study also identifies several significant threats to desert truffle hunting in the studied areas. These threats encompass both environmental and socio-economic factors that jeopardize the sustainability and cultural heritage of desert truffle hunting practices. Environmental degradation is a significant threat across all regions studied and has been consistently identified as a key factor affecting desert truffle habitats. This degradation is driven by various factors, including overgrazing, deforestation, soil erosion, and the impacts of climate change (Bradai et al., 2015a; Bates and Tucker, 2010). In Iraq and Syria, conflict-related activities have led to habitat destruction, soil erosion, and land degradation. These factors severely impact truffle ecosystems and reduce truffle availability. Similar findings by (Shavit, 2014; Gambuzza et al., 2023; Alexander, 2023) emphasise how armed conflict and associated disturbances lead to significant ecological damage, making traditional truffle hunting increasingly challenging.

Climate change poses a universal threat, with altered weather patterns affecting the growth and availability of truffles. Truffles require specific temperature ranges and sufficient moisture to mature; thus, extreme heat or drought can lead to reduced yields or even complete failure in some areas (Morte et al., 2021; Bradai et al., 2015a). Additionally, irregular rainfall disrupts the delicate balance of soil moisture, which is crucial for truffle development, further exacerbating the effects of climate change on truffle ecosystems (Bates and Tucker, 2010). Extreme weather events, such as floods and prolonged dry periods, have also been linked to habitat degradation and diminished truffle yields, particularly in Mediterranean and Middle Eastern regions (Bates and Tucker, 2010; Bradai et al., 2015a). Studies like those by (Bradai et al., 2015a; Pieroni, 2016) highlight the sensitivity of truffle production to climatic variations, which can lead to reduced yields and economic instability for communities reliant on truffle hunting.

Overharvesting and unsustainable harvesting practices threaten truffle populations, particularly in areas where economic pressures drive intensive gathering. For example, the rising market demand in Eastern Turkey has led to increased truffle hunting, sometimes without regard for sustainable practices. Lefevre and Hall (2001) discuss the risks associated with overexploitation, including the depletion of truffle habitats and long-term ecological impacts.

Socio-economic instability, exacerbated by regional conflicts and economic downturns, affects the livelihoods of truffle hunters. In Syria, the economic strain from prolonged conflict has led to dramatic fluctuations in truffle prices and market dynamics, impacting local economies and the ability of communities to sustain traditional practices. This aligns with observations by (Alexander, 2023) regarding the economic challenges faced by truffle hunters in conflict zones.

Changes in land use, including agricultural expansion, urbanisation, and industrial activities, pose significant threats to truffle habitats. In Sardinia, the encroachment of agricultural and urban development into traditional truffle hunting areas reduces the available habitat for truffles. (Therville et al., 2013). This highlights how such land use changes can fragment truffle habitats and limit the areas available for sustainable truffle harvesting.

The erosion of traditional knowledge, particularly among younger generations, is a major concern (Ahmed, 2023). The rich ecological knowledge associated with truffle hunting risks being lost as modern lifestyles and economic pressures pull younger individuals away from traditional practices. This threat is noted across all studied regions, with studies by (Sinthumule, 2023; Albuquerque et al., 2024) underscoring the importance of preserving and transmitting traditional ecological knowledge to ensure the continuity of sustainable practices.

The study offers important ecological and cultural insights, including the adaptation of truffle hunting practices to climate change and environmental degradation, highlighting the resilience of traditional

knowledge systems in sustaining both local livelihoods and desert ecosystems (Bates and Tucker, 2010; Bradai et al., 2015a). Additionally, the research underscores the role of intergenerational knowledge transfer and cross-cultural comparisons, shedding light on how diverse communities respond to similar environmental pressures, which can inform broader conservation and sustainability efforts.

Sharing successful sustainable practices and adapting them to local conditions could enhance truffle hunting practices across regions. Such exchanges could foster a collective approach to conservation and sustainability, a concept supported by (Samils et al., 2008; Al-Humaiqani and Al-Ghamdi, 2023).

The findings contribute to a broader understanding of desert truffle gathering and its role in local economies and cultures. These insights can be applied to similar ecological and cultural contexts worldwide, providing a framework for studying and supporting traditional practices that contribute to biodiversity conservation and economic resilience, as discussed by Owaid (2016) and Bele et al. (2018).

5. Limitations of the study

This study has several limitations that should be acknowledged. First, the reliance on self-reported economic data from truffle hunters may introduce biases, potentially affecting the accuracy and reliability of the findings. Additionally, environmental and climatic variability, which significantly influences truffle growth and distribution, was not fully accounted for in this study. Since desert truffles respond to specific ecological conditions, the generalizability of the results to other regions with different environmental factors may be limited.

Another constraint is the absence of longitudinal data, which prevents an in-depth understanding of long-term trends in truffle hunting practices, ecological dynamics, and economic shifts. A longitudinal approach would provide greater insights into changes over time and the sustainability of desert truffle harvesting. Furthermore, while this study documents the occurrence of different desert truffle species, it does not claim that each region harbors only one species. Multiple species may coexist in a single area, but due to the study's focus, detailed molecular taxonomy and comprehensive scientific classification were not explored. Future research should employ molecular and anatomo-morphological analyses to enhance species identification and classification accuracy. Lastly, the study does not extensively address conservation concerns related to desert truffle habitats and their long-term viability under changing environmental conditions. Future studies should broaden the geographic scope, incorporate molecular techniques for species differentiation, analyse the conservation status of truffle populations, and conduct more detailed economic and ecological assessments to inform sustainable management practices.

6. Conclusion

This study provides comprehensive insights into the ecological, cultural, and economic dimensions of desert truffle hunting across Iraq, Eastern Turkey, Syria, and Sardinia (Italy). Several key findings have emerged through a comparative analysis of truffle hunting practices, knowledge transmission, market dynamics, and culinary traditions. Firstly, the study highlights the rich diversity of ecological contexts and cultural practices associated with desert truffle hunting. Across the studied regions, truffle hunters rely on natural indicators such as surface cracks and the presence of specific plant species, such as the *Fumana* spp., to locate truffle habitats underground. Secondly, the research underscores the cultural significance of truffle hunting in each region, where it is deeply embedded in local traditions and culinary practices. From Iraq to Sardinia, truffles hold prestigious places in cuisine and are often used in traditional dishes, reflecting their cultural importance. Moreover, the economic contributions of truffle harvesting to local communities are substantial. Truffle sales provide significant sources of income, support local markets, and contribute to the economic resilience of rural areas across the studied regions.

Additionally, the study identifies various threats facing desert truffle ecosystems, including soil erosion, land use patterns, market dynamics, community conflict zones, and climate change. These findings underscore the urgent need for tailored conservation strategies and sustainable management practices to safeguard truffle habitats and ensure long-term viability.

This study enhances our understanding of desert truffle hunting's ecological, cultural, and economic importance and provides valuable insights for conservation efforts, cultural preservation initiatives, and economic development strategies in truffle-rich regions globally. By addressing these multifaceted aspects, future research and interventions can contribute to preserving desert truffle ecosystems and the sustainability of truffle hunting practices for generations to come.

CRediT authorship contribution statement

Mousaab Alrhmoun: Writing – review & editing, Writing – original draft, Visualization, Formal analysis, Conceptualization. **Naji Sulaiman:** Writing – review & editing, Conceptualization. **Giulia Mattalia:** Writing – review & editing, Conceptualization. **Hiwa M. Ahmed:** Writing – review & editing, Investigation. **Chadi Khatib:** Writing – review & editing, Investigation. **Yeter Yeşil Cantürk:** Writing – review & editing, Investigation. **Giovanni Zucca:** Writing – review & editing, Investigation. **Abdelkader Ammam:** Writing – review & editing. **Mushtaq Ahmad:** Writing – review & editing. **Andrea Pieroni:** Writing – review & editing, Methodology, Conceptualization.

Ethical declaration

The Code of Ethics of the International Society of Ethnobiology was strictly followed, and informed consent was always obtained from each participant prior to interviews.

Data availability

The data that support the findings of this study are presented in the article.

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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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