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Bioecology and Uses of Desert Truffles (Pezizales) in the Middle East

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Abstract

Desert truffles grow naturally after rainfall during the season of Al-Wasm in arid and semi-arid districts of Saudi Arabia, Iraq, Kuwait, Qatar, Bahrain, United Arab Emirates, Syria, Jordan, Palestine, Lebanon, Egypt, Iran, Turkey, Tunisia, Algeria, Libya, and Morocco. Al-Wasm provides rainfall of more than 200 ml in September to October in the Arabian Peninsula, and is important for the early growth and appearance of desert truffles. The amount of truffles increases depending on the amount of rainfall, as in other countries. Two genera of desert truffles, *Terfezia* sp. and *Tirmania* sp., are the most abundant in the Middle East. Desert truffles have nutritional value due to their proteins, carbohydrates, fats, fibers, and low energy. Also, they have immune-modulating, hepatoprotective, antidepressant, antibacterial, antifungal, antiviral, antioxidant, and antiradical properties due to their content of phenol, carotenoid, anthocyanin, ascorbic acid, flavonoid, tannin, glycoside, ergosterol, etc. Hence, the introduction of desert truffles in the pharmacological field is important, especially in the treating of eye infections and cancer. Finally, the habitats of the truffles and the host-plants need protection as nature reserves.

Keywords: Ascomycetes, biomedical applications, *Helianthemum* sp., hypogeous fungi, tuber

Introduction

Truffles were mentioned in the ancient world by the Romans and Greeks, and many studies have taken place to obtain further information and data about several varieties of desert truffles from different locations [1]. Symbiotic truffles (*Tuber* sp.) develop underground and are related to host-plant roots of the family Cistaceae, especially the genus *Helianthemum* [2]. The term "desert truffles" is used to refer to edible hypogeous macrofungi, which grow in arid zones of the Mediterranean. Occasionally, some truffle genera found in semi-arid zones, such as *Terfezia, Tirmania, Tuber, Picoa, Delastria*, and *Loculotuber* [3]. Many studies have produced desert truffles in the laboratory, such as in Iraq [4], Iran [5,6], Kuwait, Tunisia [7] and Saudi Arabia [8].

In the Arabian region, the common name of the desert truffle is "al-fag'a", but the classic Arabic word is "al-kamah', or "kame". Most desert truffles collected from the Arabian Desert belong to 2 genera, *Terfezia sp.* and *Tirmania* sp. [9]. *Tirmania nivea* (white-colored) is called "zubadi" or "zubaidi" as a common name in some Arabian countries. It has been found to be the most preferred expensive and common type of desert truffle in this region by both groups of respondents because of its good light smell, delicacy, and soft white tissues. Commonly, the second group is including *Terfezia boudieri* (black-colored) and *Terfezia claveryi* (brown-colored), "ikhlasi" or "kholasi" [9-11]. The truffles are pale sandy brown, grey or white in color, irregularly spherical, with a slightly spongy texture, with sizes from 1 - 7 cm, without a particular smell [1]. The species of a desert truffle can be identified using morphological and microscopical properties and/or genetic analyses [12]. Also, each ascus of *Terfezia boudieri* contains 8 ascospores [13]. Black truffles are highly appreciated worldwide because of their

special taste and nice smell [14]. Eastern Turkey also has truffle species, which appear in the local markets of Gaziantep; it has a price around 320 pence a kilo [1]. Wild edible truffles and fungi are collected from the soil environment for feeding and to gain money in more than 80 countries [13] like Iraq which had a reached a high price of 52 USD/kg (65,000 IQD/kg), according to the amount in the local market [4]. Some problems occur in markets, such as spoilage of truffles, since the whole stock is sold as soon as it is collected. *Aspergillus* sp., *Mucor* sp., *Bacillus* species, and *E. coli*, found on the outer and inner parts of *Terfezia boudieri, Tirmania nivea*, and *Tirmania pinoyi*, causes spoilage of truffles [15]. Because of the lack of data about the use and biomedical applications of desert truffles, this review is written in order to increase the attention of scientific community towards its useful application.

Ecology and distribution

The gathering of desert truffles (Pezizales) is a widely practised activity in Saudi Arabia during off-road driving, leading to increased habitat damage. Restrictions on the time and methods of harvesting are needed to ensure that the activities remain sustainable [16]; thus, truffles and their host-plant need to be protected from animal pasture and agriculture, by turning those fields into natural protected areas [17]. Desert truffles are found in arid and semi-arid zones in Saudi Arabia [8], Iraq [4], Kuwait, United Arab Emirates [1], Qatar [18], Bahrain [10], Syria, Palestine, Lebanon, Jordan, Egypt [19], Iran [13,20], Turkey [17], Tunisia [21], Algeria [22], Libya [19], and Morocco [3].

Generally, desert truffles appear in limited seasons. Desert truffles develop underground in arid deserts [1]. In some regions of Bahrain, 3 species of desert truffles have been identified [10]. Also, *Terfezia boudieri* has been collected from some districts of southern Tunisia [21]. Usually, desert truffles have a symbiotic relationship with the host-plant; thus, truffles are found close to the roots of the host-plant *Helianthemum* sp. (family: Cistaceae) [1]. Studies agree that heavy rains of more than 200 mm, in mild to warm weather, locally recognized as "Al-Wasm", followed by heavy evening or early morning dewfalls, are optimal conditions for growth of desert truffles. Both thunder and lightning are considered essential requirements for truffle formation [10].

In Iraq, the Anbar desert is rich with desert truffles [4,11] such as *Tirmania* sp., which appear in **Figure 1**. In Saudi Arabia, desert truffles from the eastern provinces are recorded as being black, white, and reddish in color. They appear in local markets in November to December, dependent on rainfall amount, as in the other produced countries [1]. In Iran, desert truffles are particularly harvested during mid-winter and early spring (January to March) [13]. In Kuwaiti markets, it appears from November to January in each season, dependent on the progression of each season [1].

In Turkey, *Terfezia boudieri* appears from March to May [17]. In Iran, several species of desert truffle can be found growing in the zones of the Zanjan, Qazvin, Bandar-e Abbas, and Tabriz provinces [13]. However, in Algeria, total and specific productivities (*Terfezia arenaria*, *Terfezia claveryi,* and *Tirmania nivea*) are closely positively related to autumnal precipitation occurring during October to December. The productivity of desert truffles was found under the hyper-arid climatic conditions of the desert in Algeria [22]. Wet autumn favored a heavy yield and, conversely, dry autumn induced a scarcity of truffles, which have high prices as they are highly esteemed. An additional help is the fact that the growth of the truffle fruit body often causes cracking of the ground surface. It is worth stating that the Kuwait desert is a relatively flat sand and gravel plain, with few dunes [1].

In Algeria, desert truffles grow in heterogeneous soils of the sandy texture, moderately calcareous (10.19 %), slightly alkaline (7.87), with low organic matter (0.86 %) and slight phosphorus content [23]. In Turkey, truffle-producing soil for *Terfezia boudieri* is sand-clay and limey (54.73 % sand, 21.97 clay, 23.30 % dust, 3.78 % lime, and 1.85 % organic matter), with a pH of 7.12 and nitrogen content of 0.12 % [17]. However, some truffles are found in acidic soil, such as *Terfezia arenaria* and *Terfezia fanfani*. *Terfezia claveryi*, *Terfezia boudieri*, and *Terfezia olbiensis* grow in basic soil [3]. Both strains of *T. claveryi* and *Picoa lefebvrei* exhibit a growth mycelia-like as in drought-tolerant fungi. The increased alkaline phosphatase activity can be seen in both truffles in moderate water stress and drought conditions because of the functional adaptation of truffle mycelia. Thus, alkaline phosphatase activity can be used as an indicator of the metabolic activity of this fungus [24].

Figure 1 Desert truffles (*Tirmania* sp.) in the main market of Heet (Hit) district, Anbar, Iraq, in February 2014 by Owaid [4].

The mycorrhizal association of desert truffles

The hypogeous ascomycetes *Terfezia* sp. and *Tirmania* sp. live in mycorrhizal association with *Helianthemum lippii* (Cistaceae) [22], as seen in **Figure 2**. Moreover, *P. lefebvrei* could be a good truffle candidate for future desert truffle mycorrhizal plant cultivation programs in semi-arid Mediterranean areas [24]. *Terfezia boudieri* occurs infrequently and associates with the plant-host *Helianthemum salicifolium* [17], and *Picoa lefebvrei* and *Picoa juniper* with *H. salicifolium* [25]. Some desert truffles are found in the rhizosphere soil of *Helianthemum lippii*, higher than in soil without a host-plant [26,27].

Picoa sp. lives in symbiosis with *H. lippii*, such as in Kuwait. It is not a true truffle and is a popular fresh food, which appears after early rains. The one recipe available is highly flavored and spiced, in a similar manner to an Oman recipe. Sizes up to 10 cm are quoted [1]. The development of truffles is closely linked with high rainfall, which occurs at the start of winter. The desert truffles colonize desert depressions since geomorphological zones accumulate rainwater which promotes the growth of both truffles and their host-plants [22].

Moreover, stress induces a change in the mycorrhizal type formed, which is more intracellular under conditions of drought stress for *H. almeriense* with *Terfezia claveryi* [28]. Navarro-Rodenas *et al*. [29] suggested that the ascocarp *of T. claveryi* may, at some development stages, become independent on

nutrition from the host plant. *In vitro*, Lopez-Nicolas *et al*. [30] confirmed the ability of the compound β-cyclodextrin to stimulate the mycelial growth of *T. claveryi*. Slama *et al*. [7] succeeded in the cultivation of *Terfezia boudieri* in the field, using the mycorrhizal plant of *Helianthemum sessiliflorum* in gypsy and sandy loam soils after one year.

Figure 2 *Terfezia* sp. in mycorrhizal association with *Helianthemum* sp. (Cistaceae) [3].

Classification

The name "tuber' is the scientific name for a family of underground macro-fungi, approximately classified as truffles or desert truffles. Desert truffles are distributed in arid and semi-arid areas around zones of the Mediterranean and the Middle East [1]. **Table 1** shows the most common species found in the Middle East and the Mediterranean region, according to many studies. From 2 families, about 5 genera (*Terfezia* sp., *Tirmania* sp., *Tuber* sp., *Picoa* sp., and *Phaeangium* sp.) and 28 species of desert truffles have been recorded in these zones as common truffles. Desert truffles were known by the Romans and called "tuber", which in Latin means "hump" or "bulge", as they do in the ground when mature, and concern "true truffles". Other truffle species were discovered later. Nowadays, "desert truffle" is a term used for all hypogeous fungi. Desert truffles called "fuga" in Arabic, which is from the first sight of desert truffles on the ground [1].

Also, white truffle is famous and is called "terfez" as a common name, a derivative from its scientific name [1]. In Morocco, its common name is "terfass", "terfess" or "terfez" [3]. Desert truffles (*Terfezia* sp.) are also found in the United Arab Emirates. The Turkish name is "keme", derived from the Arabic. In Turkey, some truffles are found, such as *Tuber micheli* and *T. brumale* [1].

Desert truffles belong to the order Pezizales (Ascomycetes), but formerly belong to the order Tuberales; the Pezizaceae family (*Terfezia*, *Tirmania, Peziza*, *Pachyphloeus*, *Mattirolomyces*, *Cazia*, *Kalihariтuber*, *Eremiomyces*, *Hydnotryopsis*, *Ruhlandiella*, *Stephensia*, and *Amylascus*) and the Tuberaceae family (*Tuber, Phaeangium, Picoa, Choiromyces*, *Dingleya*, *Labyrinthomyces*, and *Reddellomyces*) [19,20,27,31]. *Terfezia* sp. and *Tirmania* sp. belong to Pezizaceae and *Tuber* sp. to Tuberaceae [31]. Also, other species of truffles include *Terfezia claveryi*, *T. arenaria*, *T. oligosperma*, *Tirmania africana, Tuber nitidum*, and *Tuber asa* [32]. Generally, *Terfezia* sp. disappeared in some deserts like Desert of North America [33]. But from a genetic point of view, *Terfezia claveryi* Chatin 1891 is equal to *T. hafizi* Chatin 1892 [34]. A close genetic relationship between *Tirmania* sp. and *Terfezia* sp. has been reported. They may develop a hypogeous habit as an adaptation to heat and drought in Middle Eastern ecosystems [35].

Table 1 Some species of desert truffles, order Pezizales [19,20,27,31-35].

Family	Genera	Species
Pezizaceae	*Terfezia* sp.	*Terfezia albida* *Terfezia arenaria* *Terfezia boudieri* *Terfezia canariensis* *Terfezia claveryi* *Terfezia combonii* *Terfezia crack* *Terfezia eliocrocae* *Terfezia extremadurensis* *Terfezia fanfani* *Terfezia ledifolium* *Terfezia leptoderma* *Terfezia metaxasi* *Terfezia olbiensis* *Terfezia oligosperma*
	Tirmania sp.	*Tirmania africana* *Tirmania nivea* *Tirmania pinoyi*
Tuberaceae	*Tuber* sp.	*Tuber aestivum* *Tuber asa* *Tuber brumale* *Tuber indicum* *Tuber melanosporum* *Tuber micheli* *Tuber nitidum*
	Picoa sp.	*Picoa juniperi* *Picoa lefebvrei*
	Phaeangium sp.	*Phaeangium lefebvrei*

Chemical composition and nutritional value

Although desert truffles are consumed mainly for tradition and for their pleasant taste, they have significant amounts of proteins and very high amounts of antioxidants (phenols), which make them important in terms of nutritional value [3]. The following **Table 2** is a summary of some studies about the nutritional value of some species of desert truffles, including moisture, proteins, carbohydrates, fat, crude fiber, and ash contents. *Terfezia boudieri* (Pezizaceae) is used both for food and for traditional medicine [36]; it has traditional uses (for food and aphrodisiacs) and the eating quality is excellent [17]. Desert truffles are rich in antioxidants and could be used as a food supplement [37]. *Terfezia boudieri* is rich in carbohydrates, proteins, fat, fibers, ash, and total phenolic content, and poor in energy (about 34 - 65 kcal/100g). *Terfezia* sp. has a magnesium element of 182.3 mg/100 g, based on the dried truffle. Also, it has a vitamin C content of less than 1 g/100g (based on the dry weight). Thus, *T. boudieri* can be used as an important natural food [38] and as a source for natural health products [36].

The chemical composition and nutritional quality of Iraqi truffles, *Terfezia boudieri*, *Terfezia claveryi*, and *Tirmania nivea* are a good source of about 18 essential amino acids, like glycine, alanine, phenyl alanine, arginine, aspartic acid, glutamic acid, histidine, cystine, methionine, threonine, serine, lysine, isoleucine, leucine, proline, tyrosine, valine, and tryptophan. On the other hand, desert truffles are rich in both saturated and unsaturated fatty acids. *Terfezia boudieri* is rich in fatty acids such as pentadecanoic, margaric, stearic, arachidic [39], behenic, palmitic, palmitoleic, stearic, oleic, linoleic, and

linolenic acids [40]. *Tirmania nivea* contains palmitic acid, stearic acid, oleic acid, and linoleic acid. *Tirmania pinoyi* contains fatty acids such as myristic, margaric, stearic, nonadecanoic, arachidic, heneicosanoic, behanic, euric, palmitoleic, oleic, and linolenic acids [39].

Ascorbic acid (vitamin C) level in *Tirmania nivea* is about 1 - 1.8 mg/100g, *Terfezia claveryi* 1.8 - 2 mg/100g, and *Terfezia boudieri* 4.8 - 4.9 mg/100g [11], and these species contain the following elements: N, P, K, Ca, Mg, Na, Fe, Mn, Cu, and Zn, dependent on the truffle species [41]. *T. boudieri* contains flavonoids such as myricetin, kaempferol, naringenin (not found in most mushrooms), and resveratrol [40]. The free ergosterol content of *Tuber* sp. ranges from 1.28 to 1.80 mg/g, and the total phenolic compounds (*o*-coumaric and *p*-coumaric acids) varies from 1.20 to 1.88 mg/g of dried matter [42]. This truffle also has phenolic compounds such as gallic acid, homogentisic acid, protocatechuic acid, *p*-hydroxybenzoic, 3,4-dihydroxybenzaldehyde, *p*-coumaric acid, *o*-coumaric acid, hydroxybenzoic acid, and hydroxycinnamic acid [42].

Table 2 Chemical composition of desert truffle *Terfezia* sp. (g/100g based on the dried matter).

Truffles	Moisture	Carbohydrates	Protein	Fat	Ash	Fibers	References
Terfezia boudieri	75.4	ND	25.1	4.3	6.1	11.3	[11]
Terfezia boudieri	76.1	ND	24.7	4.6	6.3	12.6	[11]
Terfezia boudieri	10.25	ND	20.13	3.45	7.8	ND	[40]
Terfezia boudieri	80-90	4.8-11.6	1.4-2.7	0.8-1.7	1.0-1.9	ND	[43]
Terfezia claveryi	74.9	ND	23.0	3.1	5.2	9.8	[11]
Terfezia claveryi	75.2	ND	23.0	3.5	4.6	8.0	[11]
Terfezia claveryi	ND	ND	15.95	6.95	4.25	ND	[44]
Terfezia claveryi	ND	ND	19.2	6.9		ND	[45]
Terfezia claveryi	ND	16.7	8.0	ND	8.9	ND	[46]
Terfezia claveryi	ND	ND	19.6	4.7	4.5	7	[47]
Terfezia sp.	73-78	11-17	4-5	0.6-1.8	0.8-1	1.4-2.6	[3]
Terfezia sp.	ND	1.4	2.7	2.2	19.9	ND	[41]
Tirmania nivea	ND	21.5	13.8	ND	4.9	ND	[46]
Tirmania nivea	ND	ND	72.2	2.8	5.4	13.2	[47]
Tirmania nivea	70.0	ND	26.4	6.5	4.1	8.1	[11]
Tirmania nivea	73.5	ND	25.8	6.2	5.2	6.5	[11]
Tirmania pinoyi	82.3	82.59	8.1	4.1	5.2	ND	[48]
Tirmania pinoyi	ND	24.9	10.5	ND	5.6	ND	[46]
Tirmania sp.	ND	1.9	1.9	3.3	5.8	ND	[41]
Picoa juniperi	ND	ND	22.5	19.9	8.2	ND	[44]

Legend: ND: not detected.

Medicinal uses

The medicinal value of desert truffles includes many biomedical applications (**Table 3**). Desert truffles have a very high amount of various antioxidants [3,38]. Moroccan truffles *Tirmania nivea* have antioxidant/antiradical activity [49]. Iraqi truffles (white and black) were found to inhibit the replication of Tomato Mosaic Virus [41].

T. claveryi and *T. nivea* can be used as a source of natural therapeutic agents in the treatment of eye infections which are caused by some resistant bacteria [8], such as the species *Pseudomonas aeruginosa* and the species *Staphylococcus aureus* [50]. Methanolic extracts of *Terfezia boudieri* have antioxidant and antiradical properties due to the high total phenols, total carotenoids, and anthocyanin contents; thus, it is used as a pharmaceutical agent [37]. Extracts of *T. boudieri* have antimicrobial activity against Gram negative and Gram positive bacteria and yeasts using a micro dilution method [38].

The antimicrobial activity of an aqueous extract of *Terfezia claveryi* aqueous extract inhibited about 66.4 % against *S. aureus*, *in vitro* [51]. Acetone extracts of *T. boudieri* have excellent antimicrobial and antifungal activities against *Streptococcus pyogenes*, *Bacillus subtilis*, and *Candida albicans* [36]. Also, *Terfezia* sp. was found to be active against plant pathogenic fungi [52].

A methanolic extract of *Tirmania pinoyi* showed *in vitro* antioxidant and antimicrobial activities towards *S. aureus* [48]. Iraqi truffle (*Terfezia* sp. and *Tirmania* sp.) showed a high inhibitory activity in extracted tannins and glycosides against the growth of pathogenic bacteria such as *Ps. aeruginosa*, *K. pneumonia*, *S. aureus*, *E. coli*, *Proteus* sp., *Enterobacter* sp., and *Aeromonas* sp., and fungi such as *Fusarium* sp., *A. nigar*, and *A. terrus* [41], due to their phenolic compounds content [42]. *Terfezia* sp.and *Tirmania* sp. showed anticancer activity, immune-modulating activity, antiviral activity, hepatoprotective activity, and antidepressant activity [53,54]. Finally, desert truffles are important as a simultaneous food and drug, especially in the treatment of eye infections without side-effects [8].

Table 3 Biomedical application of desert truffles.

Truffle name	Active compounds	Biomedical applications	References
Terfezia sp.	Crude water extract	Treatment of eye infections	[8]
Tirmania sp.	Crude water extract	Treatment of eye infections	[8]
Terfezia boudieri	Acetone extract	Antibacterial and antifungal activities	[36]
Terfezia boudieri	Phenols, carotenoids, and anthocyanin	Antioxidant and antiradical activities	[37]
Terfezia boudieri	Crude extract	Antibacterial and anticandidal activities	[38]
Terfezia boudieri	Flavonoid	Radical scavenging activity	[40]
Tirmania sp.	Tannins and glycosides	Antibacterial, antifungal, and antiviral activities	[41]
Terfezia sp.	Tannins and glycosides	Antibacterial, antifungal, and antiviral activities	[41]
Tuber aestivum	Ergosterol and phenolic	Antioxidant activity	[42]
Tuber melanosporum	Ergosterol and phenolic	Antioxidant activity	[42]
Tuber indicum	Ergosterol and phenolic	Antioxidant activity	[42]
Tirmania pinoyi	Tocopherol free sugars, and fatty acids	Antioxidant and antibacterial activities	[48]
Tirmania nivea	Phenols	Antioxidant and antiradical activities	[49]
Terfezia claveryi	Stigmasterol, β-sitosterol, squalene, and lupeol	Anticancer and antioxidant activities	[53]
Terfezia sp. and *Tirmania* sp.	Varied	Immune-modulating, antiviral, hepato-protective, and antidepressant activities	[54]

Conclusions

In this review, desert truffles were identified using morphological and/or genetic characteristics. *Terfezia* sp. and *Tirmania* sp. are the most abundant truffles in Middle Eastern countries. Desert truffles grow naturally after rainfall during Al-Wasm in arid and semi-arid districts of Saudi Arabia, Iraq, Kuwait, Qatar, Bahrain, United Arab Emirates, Syria, Palestine, Lebanon, Jordan, Egypt, Iran, Turkey, Tunisia, Algeria, Libya, and Morocco. The number of truffle increases depending on the amount of rainfall, as in other countries. Desert truffles have nutritional value and immune-modulating, hepatoprotective, antidepressant, antibacterial, antifungal, antiviral, antioxidant, and antiradical properties, due to their phenol, carotenoid, anthocyanin, ascorbic acid, flavonoid, tannin, glycoside, and ergosterol content; thus, the introduction of desert truffles in the pharmacological field is important, especially for treating eye infections and cancer. Finally, the habitat of the truffles and the host-plants needs protection as nature reserves.

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