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Desert truffle biodiversity, biology, ecology, and mycorrhizal connection in Morocco

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Abstract

In Morocco, there are many different types of desert truffles, including *Terfezia*, *Tirmania*, *Delastria*, *Picoa*, and *Tuber*. The Maamora Forest, Doukkala-Abda Sahel, northeast of Morocco, and the Moroccan Sahara are the four truffle regions where the geographical distribution of these ascomycetes has been noted most frequently. In addition to being a great source of protein, amino acids, carbon hydrates, and fiber, desert truffles are also regarded as a valuable source of antibiotic alternatives for pathogenic bacteria that are resistant to antibiotics. Due to the widespread appreciation of truffles, we could use these resources to develop local populations, especially in truffle-producing regions. The biodiversity of desert truffles in Morocco and other Maghreb countries is one of the characteristics of truffles that are briefly discussed in this paper review. Ecology, biology, geographical spread, and final considerations include the mycorrhizal association of truffles, biochemistry, and physiology.

Keywords: biodiversity; biochemistry; desert truffles; mycorrhizal association; taxonomy

Introduction

Several studies have been conducted on the global importance of truffles in terms of agriculture, medicine, and economics. Although some research finding outline fungi are heterotrophic organisms, acquiring organic matter through three main modes of nutrition (symbiotic, parasitic and saprotrophic). While many species of saprophytic fungi have been successfully cultivated for a long time Oei (2003), for example, Judas ear (*Auricularia auricula*) cultivated in China since 600 before Jesus Christ or *Agaricus bisporus* dating back to 17th century, other types of fungi are more difficult to cultivate (Hall and Zambonelli, 2012). The first to understand the symbiotic nature of chimeric associations between roots and fungi, but described long ago, he named mycorrhizae from the Greek Mukè, fungus, and rhizome, root (Frank, 2005). Like all fungi, truffles are unable to synthesize their organic matter and use solar energy, due to the absence of chlorophyll as a pigment responsible for photosynthesis, they live in association with plants for their supply of organic substances and sugars that are important in exchange for minerals with their hosts. The reciprocal exchange between fungi and

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their hosts defines the relationship of symbiosis. They are characterized by a mycelium that travels through the soil looking for food, penetrating the root system of the plant and causing the disruption of its structure. The association between the host plant's secondary roots (rootlets) and the mycelium leads to the formation of a structure essential for exchanges: The mycorrhiza. On the roots of the family Cistaceae, which includes the annual and perennial species of the genera *Cistus*, *Tuberaria*, and notably *Helianthemum*, the mechanism of symbiotic connection is of an ectomycorrhizal and endomycorrhizal type (Fortas and Chevalier, 1992; Slama *et al*., 2010; Zitouni-Haouar *et al*., 2014). In this symbiotic relationship, the plant provides the fungus with carbon, which ensures its hydromineral nutrition. Additionally, both partners protect each other from the aggressions of the soil. Therefore, in mycorrhizal species, cultivation of a single fungus is difficult, if not impossible, and is limited to the vegetative stage if the entire plant-fungus relationship is not understood. Therefore, in light of this brief introduction, it is important to focus our research on magical resources: Truffles. Truffles are ascomycetes belonging to the order of Pezizales the hypogeous fructification (Yao *et al*., 1995). They grow and develop in the Middle East and the Mediterranean basin, mostly in semi-arid and desert regions, and are edible (Bradai *et al*., 2015), on calcareous soil rich in calcium (Bokhary and Parvez, 1992). Terfasse, or desert truffles, are ascomycetes that only develop in arid and semi-arid regions. Desert truffles have symbiotic relationships with the roots of trees like *poplar*, *oak*, and *hazelnut* (Harrison, 1997). Generally, the most common terfess host plants are herbaceous or perennial *Helianthemums* (Khabar, 2014).

The most essential qualities of truffles are their environmental and health benefits. They are full of proteins, vitamins, minerals, carbohydrates, and fats (Bokhary *et al*., 1987; Bokhary and Parvez, 1993). Some types of truffles, like *Tuber melanosporum* (black perigord truffle), *Tuber aestivum* (summer truffle), *Tuber magnatum* (white truffle), and others that people like for their smell (Diaz *et al*., 2003), are also appreciated. They have a symbiotic relationship with the roots of trees such as poplar, oak, and hazelnut (Harrison, 1997). Generally, the most common terfess host plants are herbaceous or perennial *Helianthemums* (Khabar, 2014).

Desert truffles are popular for their health and nutritional benefits. A study aimed to produce fungal biomass from *Tirmania nivea*, a natural renewable resource, using an artificial growth medium. The fungal biomass was grown in potato dextrose broth and analysed for antimicrobial activity. The crude extracts showed potential as antifungal, antibacterial, antiviral, anticancer, antioxidant, anti-trypanosomal, and anti-inflammatory agents. The study highlights the potential of desert truffles as a natural renewable resource (Khaled et *al*., 2021).

Mycorrhiza results from the association established between vascular plants and their symbiotic soil fungi. Mycorrhiza improves the ability of plants to resist environmental factors, including nutrient deficiency, water stress, and soil nuisance (Barea *et al*., 2011). In Morocco, research works related to truffles are not yet well developed, they are of taxonomic, floristic (Chatin, 1891; Khabar, 2002), phytosociological, cytological, ultrastructural, and geographical orders (Harki *et al*., 2010; Khabar, 2014).

It was found that mycorrhizas were closely related to desert truffles. In spite of the significance of mycorrhizal connection to desert truffles, there have been little investigations in this subject. As a result, the major goal of this study is to document the recent studies of knowledge about mycorrhiza-desert truffle interactions, identify important gaps in knowledge, and provide solutions to fill these gaps in the future studies.

Materials and Methods

To the objective of this study, a methodology based on main steps was chosen: A documentary research on knowledge of Moroccan truffles: Google scholar, PubMed, ScienceDirect, SpringerLink, Web of Science and Scopus.

The desert truffles and taxonomy

The *Terfezia*, *Tirmania*, *Picoa*, *Carbomyces*, *Elderia*, *Eremiomyces*, *Kalaharituber*, *Mattirolomyces*, *Mycoclelandia*, *Stouffera*, and *Ulurua* genera are the taxa that make up the family of desert truffles (Kovács and Trappe, 2013). The identification of truffles is based on taxonomic criteria: The shape of the spores, the size, the ornamentation, and the structure of the gleba and the peridium (Mello *et al*., 2006).

Most of the morphological studies to differentiate truffle species have been done on the fruiting body, the ascocarp. Concerning the ascocarp (truffle itself), these morphological differences are observed at different levels: 1) macroscopic (size of the ascocarp, colour of the gleba, aspect of the peridium) and 2) microscopic (size of the gleba, aspect of the peridium). Gleba, aspect of the peridium and 2) microscopic (morphology of the asci and spores). The size of the fruiting body depends of course on the environment but is also species-dependent. They are also distinguished by their chemical and molecular characteristics. Indeed, the shape of the ascocarps is spherical (subglobose or piriform, glabrous) characterizing the species of *T. nivea* (Jamali and Banihashemi, 2012). Their skin is light brown or creamy white, and the pith, called gleba, is initially white or yellowish and becomes brown with age. Generally, the fruiting body is characterized by a spherical pear-shaped form of width 5-12 (20) cm, lobed or irregular. The outside is white, cream, ochre, rusty-ochre, or brown-ochre. In maturity, the gleba is compact, white, and elastic, with light pink or ochre spots and subtle white veins. It has a lovely odor. In contrast, the fruiting bodies of *T. arenaria* are 3-12 (15) cm wide, usually with a rudimentary and irregularly spherical base. The outer part is dry, beige, ochre-beige, or pink-beige and in most cases lobed, Reddish-brown, grayish-blackish brown, or brown at maturity. The gleba is characterized by yellow colours and a slightly spermatic smell (Loizides *et al*., 2012). The *T. claveryi* ascocarps collected in Morocco had the following shapes: spherical, ovoid, and cordiform, fresh weights of between 17 and 50 g. The gleba exhibited a few millimeters of spotting, and the peridium was initially pinkish-white in hue before turning brownish-black. The fertile, round, pinkish (before turning light brown), and spherical nodules in the gleba were divided by thin, pale veins. The gleba had a firm, slightly spongy texture. Hyaline, grey, spherical ascospores (18-21 m) with an alveolus network were found inside the asci, which were ovoid (64-68-72-84 m) in form. The size and shape of the ascocarps of *Tirmania* sp. transformed from sub-globular and piriform to turbine-like, with lobes or irregular morphologies (Khabar, 2016). The four main truffle growing regions in Morocco are the North-East, the Maâmora forest, the Doukkala-Abda Sahel, and the Moroccan Sahara. There are about ten species of desert truffles in these regions belongs to the genera *Tuber*, *Delastria*, *Terfezia*, *Tirmania* and *Picoa* (Hakkou *et al*., 2022). Table 1 and 2 show desert truffle biodiversity.

Table 1. Desert truffle biodiversity in Morocco and other Arab nations

<table>
<tr><td colspan="6">Genus: Terfezia, Systematic: Division: Ascomycota / Class: Pezizomycetes / Order: Pezizales / Family: Terfeziaceae</td></tr>
<tr><th>Country</th><th colspan="2">Taxonomy of desert truffles</th><th>Biotic and abiotic factors</th><th>Harvest period</th><th>References</th></tr>
<tr><td rowspan="9">Morocco</td><td rowspan="4">Terfezia arenaria (Moris)</td><td>Tuber arenarium Moris (1829)</td><td rowspan="4">Climate: Semi-arid
Soil: acid, light sandy
Host plant: Helianthemum guttatum</td><td rowspan="4">Mid-February to early June</td><td rowspan="4">(Trappe, 1971; Malençon, 1973, Abourouh, 2011; Khabar, 2016; Harir et al., 2019; Abourouh, 2020; Hakkou et al., 2022)</td></tr>
<tr><td>Choiromyces Leonis Tul. and C. Tul. (1845)</td></tr>
<tr><td>Rhizopogon Leonis Tul. and C. Tul (1850)</td></tr>
<tr><td>Terfezia leonis Tul. and C. Tul. (1851)</td></tr>
<tr><td>Terfezia boudieri Chatin (1891)</td><td>Terfezia deflersii Patouillard (1894)</td><td>Climate: Semi-arid and arid
Soil: basic, gypseous and calcareous
Host plant: Helianthemum Lippii var. sessiliflorum and Helianthemum ledifolium</td><td>March and April</td><td>(Chatin, 1891; Khabar, 2002; Roth-Bejerano et al., 2004; Khabar, 2016; Abourouh, 2020)</td></tr>
<tr><td rowspan="2">Terfezia claveryi Chatin (1891)</td><td>Terfezia hafizzi Chatin (1892)</td><td rowspan="2">Climate: Semi-arid, Arid, pre-Saharan, and Saharan
Soil: basic, limestone or marl-gypsum soil
Host plant: Helianthemum lipii and Helianthemum apertum</td><td rowspan="2">Early March to early June</td><td rowspan="2">(Chatin, 1891; Malençon, 1973; Alsheikh, 1994; Khabar, 2002; El Akil et al., 2016; Khabar, 2016)</td></tr>
<tr><td>Terfezia hanotauxi Chatin (1895)</td></tr>
<tr><td>Terfezia leptoderma Tulasne (1851)</td><td>Choiromyces leptodermus Tulasne and C. Tulasne (1845)</td><td>Climate: Semi-arid, Arid
Soil: sandy acid or more compact, clayey and siliceous
Host plant: Helianthemum guttatum</td><td>The third week of February and until May</td><td>(Díez et al., 2002; Khabar, 2002; El Akil et al., 2016; Abourouh, 2020)</td></tr>
<tr><td>Terfezia olbiensis Tul. and C. Tul. (1845)</td><td>Choiromyces olbiensis Tul. and C. Tul. (1845)</td><td>Climate: Arid
Soil: sandy
Host plant: Pinus halepensis</td><td>December and January</td><td>(Alsheikh, 1994; El Akil et al., 2016)</td></tr>
<tr><td colspan="6">Genus: Tuber, Systematic: Division: Ascomycota / Class: Pezizomycetes /Order: Pezizales / Family: Tuberaceae</td></tr>
</table>

Country	Taxonomy of desert truffles		Biotic and abiotic factors	Harvest period	References
Morocco	*Tuber asa* Tulasne (1851)	*Terfezia gennadii* Chatin (1896) *Tuber lacunosus* Mattirolo (1900) *Tuber gennadii* (Chat) atouillard (1903)	Climate: Semi-arid Soil: acidic soils sandy or more compact, clayey and siliceous soils Host plant: *Helianthemum guttatum*	End of the month of February until the end of April	(Khabar, 2002, 2016; Abourouh, 2020)
Morocco	*Tuber oligospermum* (Tul. and Tul.) Trape (1979)	*Terfezia oligosperma* Tul and Tul. (1851) *Delastreopsis oligosperma* (Tul.) Matt. (1904)	Climate: Semi-arid Soil: sandy Host plant: *Pinus pinaster* var. atlantica	December until April or May	(Khabar, 2002, 2016; Abourouh, 2020)
Morocco	*Tuber gennadii* (Chatin) Patouillard (1903)	*Terfezia gennadii* Chatin (1896) *Tuber lacunosum* Mattirolo (1900) *Loculotuber gennadii* (Chatin) Trappe, (1992)	Climate: Semi-arid Soil: sandy soils or more compact, clayey, and siliceous Host plant: *Helianthemum guttatum*	March to June	(Abourouh, 2020)
Genus: *Tirmania,* Systematic: Division: *Ascomycota* / Class: *Pezizomycetes* / Order: *Pezizales* / Family: *Terfeziaceae*					
Country	Taxonomy of desert truffles		Biotic and abiotic factors	Harvest period	References
Morocco	*Tirmania Nivea* (Desf.) Trappe, 1971	*Tuber niveum* Desf. (1823) *Terfezia ovalispora* Patouillard (1890) *Tirmania ovalispora* Pat. (1892) *Tirmania africana* Chatin (1892)	Climate: Arid, Pre-Saharan, and Saharan Soil: sandy Host plant: *Helianthemum hirtum* and *Helianthemum lipii*	From February through May	(Malençon, 1973; El Aji, 1999; El Akil *et al*., 2016)

	Tirmania pinoyi (Maire) Malençon (1973)	*Terfezia pinoy* Maire, (1906)	Climate: Arid, Pre-Saharan, and Saharan Soil: sandy Host plant: *Helianthemum hirtum* and *Helianthemum lipii*	From February through May	(Malençon, 1973; El Aji, 1999; El Akil *et al*., 2016)
Genus: *Delastria,* Systematic: Division: *Ascomycota* / Class: *Pezizomycetes* / Order: *Pezizales* / Family: *Terfeziaceae*					
Country	Taxonomy of desert truffles		Biotic and abiotic factors	Harvest period	References
Morocco	*Delastria rosea* Tulasne (1843)	*Terfezia rosea* (Tul.) Torrend, (1907)	Climate: semi-arid Soil: sandy Host plant: *Pinus pinaster* var. atlantica	From February through May	(Khabar, 2002, 2016; Abourouh, 2020)
Genus: *Picoa* Systematic: Division: *Ascomycota* / Class: *Pezizomycetes* / Order: *Pezizales* / Family: *Helvellaceae*					
Country	Taxonomy of desert truffles		Biotic and abiotic factors	Harvest period	References
Morocco	*Picoa juniperi* Vittadini (1831)	*Picoa juniperina* Tulasne (1851)	Climate: Arid, Pre-Saharan, and Saharan Soil: calcareous Host plant: *Helianthemum lipii*	February to April	(El Aji, 1999; Khabar, 2016)

Table 2. Real truffles "T*uber*" in Morocco

Country	Taxonomy of desert truffles		Biotic and abiotic factors	Harvest period	References
Morocco	*Tuber Melanosporum* Vittadini, 1831	*Tuber brumale* Pulpa obscura, odora P. Micheli (1729)	Climate: Semi-arid and subhumid to humid Soil: well-drained and porous aerated limestone Host plant: *Quercus ilex*	November through March	(Laqbaqbi, 2020)
		Tuber gulosorum (Scopoli) Pico (1788)			
		Tuber nigrum Bulliard (1788)			
		Tuber cibarium nigrum Bulliard (1791)			
		Tuber cibarium Persoon, (1801)			
		Tuber cibarium Bulliard Fries (1823)			
		Tuber gulonum (Corda) Paoletti (1889)			
	Tuber Borchii Var. sphaerosperma Malençon (1973)	*Tuber sphaerospermum* Malençon (2006)	Climate: Semi-arid Soil: sandy Host plant: *Pinus halepensis* and *Pinus pinea*	April and May	(Malençon, 1973; Abourouh, 2020)
	Tuber rufum Pico, 1788	*Tuberum tertium* genus Mattioli (1544)	Climate: subhumid and humid Soil: calcareous	June to November	(Malençon, 1973)
		Tuber cinereum Tul et C. Tul. (1844)			
		Tuber lucidum			

		Bonnet (1884)	Host plant: *Quercus ilex*		
		Tuber caroli Bonnet (1885)			
		Tuber rutilum R Hesse, (1894)			
Country	Taxonomy of desert truffles		Biotic and abiotic factors	Harvest period	References
Morocco	*Tuber uncinatum* Chatin (1887)	*Tuber Aestivum* Vittadini (1831)	Climate: subhumid and humid Soil: Acidic soils sandy Host plant: *Quercus ilex*	September to January	(Malençon, 1973)
	Tuber brumale Vittadini (1831)	*Tuber brumale* Vittadini var. moschatum Ferry de la Bellone (1888)	Climate: humid Soil: calcareous Host plant: *Quercus ilex*	November to March	(Olivier *et al*., 2018)
Algeria	*Tirmania*	*Tirmania pinoyi* (Maire)	*Helianthemum lippii* (L.) Dum.- Courset		(Bradai *et al*., 2013)
Tunisia	*Terfezia*	*Terfezia boudieri* Chatin	*Helianthemum sessiliflorum* Desf.		(Hamza *et al*., 2016)
Egypt	*Terfezia*	*Terfezia arenaria* (Moris) Trappe	*Helianthemum lippii* (L.) Dum. Courset		(El-Kholy, 1989)
		Terfezia claveryi Chatin			
	Tirmania	*Tirmania nivea* (Desf.) Trappe			
Bahrain	*Tirmania*	*Tirmania nivea* (Desf.) Trappe	*Helianthemum kahiricum* Del.		(Mandeel and Al-Laith, 2007)
	Phaeangium	*Phaeangium lefebvrei* Pat.			
Kuwait	*Tirmania*	*Tirmania nivea* (Desf.) Trappe	*Helianthemum kahiricum* Dei.		(Alsheikh and Trappe, 1983)
Jordan	*Terfezia*	*Terfezia claveryi* Chatin	*Helianthemum* Spp.		(Janakat *et al*., 2004)
Iraq	*Terfezia*	*Terfezia claveryi* Chatin	*Helianthemum* Spp.		(Dahham *et al*., 2016)
Saudi Arabia	*Terfezia*	*Terfezia claveryi* Chatin	*Helianthemum vesicarium* Boiss. *Helianthemum kahiricum* Del. *Helianthemum lippii* (L.) Dum.		(Sawaya *et al*., 1985; Bokhary *et al*., 1987; Hashem and Al-Obaid, 1996; Janakat *et al*., 2005; Schillaci *et al*., 2017)
		Terfezia boudieri Chatin			
	Tirmania	*Tirmania nivea* (Desf.) Trappe			
		Tirmania pinoyi (Maire)			
	Picoa	*Picoa juniperi* Vittad.			
		Picoa lefebvrei (Pat.) Maire			
		Phaeangium lefebvrei (Pat.) Maire			

Geographical distribution of truffles

Geographically, truffles are spread in arid and semi-arid areas around the Mediterranean Basin and the Middle East (Bradai *et al*., 2015). The study conducted in Morocco by Khabar (2002), announces three sites that have been designated as truffle areas, are the forest of Maamora which is located in the northwest, east of Rabat the soil is acidic in nature, and a semi-arid climate. The second area located in the east and southeast of Morocco, it consists of the eastern high plateau of Morocco which is characterized by a soil of limestone nature and an arid climate and sub-Saharian. The last area is the plain of Abda located east of the city of Safi, this area is characterized by limestone soil and a semi-arid climate. Thus, according to Abourouh (2011) and Khabar (2016), four major areas have been identified truffle growing in Morocco, they are the Oriental, the Maâmora forest, the Sahel of Abda-Doukkala, and the Moroccan Sahara.

Ten species may be found in Morocco's semi-arid and arid areas, where yearly rainfall is low and average temperatures are high (Zniber *et al*., 2022). They are associated to *Cistus*, *Pinus*, and many other species, but the *Helianthemum* is where they are more frequently found (Zniber *et al*., 2022). Some of Morocco's desert truffles are found in the country's south. The first is terfes red du Tafilalet, also known as *T. claveryi* (*T. hafizi* Chat.). It is situated close to Ksar Es-Souk, Boudenib, and Figuig (Abou Lakhal and Bni Guil areas), in the regions of Tendrala, Ain Beni Mather, Erfoud, Bouarfa, and Bou Bernous (Khabar, 2016; Bermaki *et al*., 2017). Using *H. lipii* as a host plant, it can be collected following the rains that occur from March to May. Additionally, *T. boudieri* can be found a few kilometres east of Safi in the Had Hrara and Abda plain in the Oualidia area. Additionally, it can be found in the areas around Ain Beni Mather and Erfoud. More significantly, it can be found in the March and April harvested *Helianthemum* species *H. lipii* and *H. ledifolium* in the desert plains. *Ti. nivea* and *Ti. pinoyi* have been discovered as two additional species that fall under the umbrella of the genus *Tirmania*. Ain Beni Mather, Tendrara, Bouarfa, Erfoud, Figuig, and Rissani are among the south-easterly areas where they are dispersed. The crop season lasts from early December to early March when *H. hirtum* serves as the host plant.

In other countries Tunisia, Algeria, Egypt, Libya, Iraq, Saudi Arabia, Kuwait, Syria, Palestine and Iran are among the countries where desert truffles are found. Additionally, they are found in the southern regions of France, Spain, Italy, Greece, and Portugal, in the Mediterranean Basin (Khabar, 2016). *T. claveryi* is found in the African nations of Libya (Hashem *et al*., 2018), Tunisia, Algeria, Egypt (Khabar, 2016), and even in France and Spain (particularly in the southern semi-desert regions) (Khabar, 2016). Additionally, *T. boudieri* can be found in Libya and Egypt, sometimes in Tunisia and Algeria under the *Helianthemum lipii*, and occasionally under the *Rhatherium suaveolens* Desf.

In Tunisia, the desert truffles are mainly found in the country's center and south.

In Algeria, truffles are grown in the regions of Bechar (Taghit, Kenadssa, Tabelbala, Béni Abbes, Abadla), Ouargla (Oued Mya), Tindouf, Timimoun, Touggourt, Tamanrasset (Montagnes du Hoggar), El Golea, Ghardaïa, Biskra, Djelfa, Batna, Boussaâda, Saida, Naama, Mécherai, Laghouat (Chevalier, 1984).

In France, Spain, Portugal, Hungary, and northern Serbia one finds *Terfezia boudieri, Terfezia claveryi*, *Terfezia olbiensis, Terfezia leptoderma*, and *Terfezia arenaria* (Maire, 1906; Malençon, 1973; Dıaz *et al*., 2003; Culleré *et al*., 2010).

In addition, the following species are found in Turkey, Syria, Lebanon and the Middle East, *Picoa lefebvrei*, *Picoa juniperi*, *Tirmania nivea*, *Tirmania pinoyi*, *Terfezia boudieri*, *Terfezia arenaria*, *Terfezia leptoderma*, and *Terfezia claveryi* were identified by Alsheikh and Trappe in 1983.

Four truffle species were identified in the non-Mediterranean Asian countries like Saudi Arabia, Bahrain, Qatar, and Kuwait during the census. The desert white truffle species *Tirmania nivea* is locally known as Zubaidi. Consumers prefer the latter species over the other. *Terfezia boudieri*, *Terfezia claveryi*, and *Picoa lefebvrei* are two types of brown truffles known locally as kholaissi (Al-Laith, 2010).

Truffle biology

A recent study carried out by Desert truffles are hypogeous fungus that create a symbiotic relationship with *Cistaceae* family plants and the reproductive methods and biochemical mechanisms behind the ectendomycorrhizal relationship of these fungi are unknown (Marqués-Gálvez *et al*., 2021). *Terfezia claveryi* Chatin and *Tirmania nivea* Trappe, two highly prized edible desert truffles, have had their genomes sequenced and compared to those of other *Pezizomycetes*. In the same context. Marqués *et al*. (2021) identified fungal genes involved in sexual reproduction in desert truffles as well as genomic and secretomic features distinct from other Pezizomycetes in desert truffles, such as the proliferation of a significant number of gene families with unknown Pfam domains and a number of small, species or desert truffle-specific secreted proteins that were differentially managed in the symbiosis. The factors that induce sexual reproduction of the truffle are not known, and many burned sites, where the vegetative presence of the truffle has been verified, remain non-productive. Laboratory studies on unicellular and filamentous Ascomycetes have highlighted the importance of factors such as substrate modification (including nutrient restriction), light, pH and atmospheric conditions, inducing either vegetative or sexual reproduction (Debuchy *et al*., 2010). Very few studies have identified the factors leading to fructification in macromycetes mushrooms, but it appears that abrupt changes in temperature, nutrient availability, and water availability may all have an impact on the growth of the mycelium and lead to the formation of fructifications (Kües and Liu, 2000; Oei, 2003). According to Pacioni *et al*. (2014) hydric stress encourages the commencement of young ascocarp in truffe, and the mycelium's strong activity (measured by CO_2 emission) precedes their creation. In general, it appears that a moderated water stress is advantageous to the vegetative growth of the truffe (rate of mycorrhization). Olivera *et al.* (2014) indicating that careful irrigation is necessary to encourage the maintenance of truffles.

Development of the ascocarp and method of reproduction of the truffe

As is typical for ascomycetes, the mycelium haplotype forms the ectomycorrhizas of truffe (Rubini *et al*., 2014). The genes present locally at the level of the ectomycorrhizas will act as the individual mother during reproduction, forming the gleba, the sterile chair of the ascocarp, in which they participate through nourishment. An isotopic CO_2 measurement experiment allowed researchers to track the carbon produced by the host tree's photosynthetic process, demonstrating that the ascocarp's carbon-based nutrition comes from the tree through the ectomycorrhizas, which is connected to the ascocarp through previously unrecognized connections (Le Tacon *et al*., 2013). The source of other compounds (phosphate, azote, etc) has not been able to be identified by this method, although they may be directly absorbed into the soil by the truffle mycelia (Barry *et al*., 1994) and/or involve bacteria, such as azote fixators of the *Bradyrhizobiaceae* family (Antony-Babu *et al*., 2014) for *T. magnatum* (Barbieri *et al*., 2010).

The ascocarp, which is enclosed by the gleba, contains thousands of intensely pigmented spores that make them resistant to passing through a digestive tube (Piattoni *et al*., 2014). It has been established that these spores are the result of heterothallic sexual reproduction (Rubini *et al*., 2011), despite Truffe's long-held homothallic reputation. This hypothesis had been advanced due to the absence of heterozygosis observed in one of the first studies using codominant genetic markers (two markers for microsatellites that allow for the detection of different alleles, or heterozygosis (Bertault *et al*., 2001). The possibility of a crossover between two individuals within this haploid species would thus have been made more likely by the presence of heterozygotes. However, it is likely that only the gleba's ADN was extracted and/or that the two microsatellite markers used were not sufficiently polymorphic (carried little genetic variability). A few years later, the sequencing of the truffe genome souche haploid Mel28 (Martin *et al*., 2010). The existence of a sexual allele was shown (MAT1-2-1, abbreviated as MT2 that is indicative of heterothallism. The sexually antagonistic sequence MAT1-1 (abbreviated as MAT1) has subsequently been identified (Rubini *et al.,* 2011). When the ADN of the spores is extracted using a specific procedure, which 1) concentrates the ascospores and 2) rips apart the asques and the paroi of the spores, it confirms that the truffe is a heterothallic mushroom (Paolocci *et al*., 2006). As a result, the genotype of the mother is determined by working with the gleba's ADN, and the genotype of the father can be determined by comparing the genotype of the mother to the zygote, which was obtained by working with the spores ADN. Because other species cannot directly achieve the parental genotypes, Truffe's particularity makes it an original biological function model.

Ecological studies on desert truffles

In the Great Sahara of Morocco, the location of desert truffles is proven in soils of homogeneous texture, such as calcareous, aerated, and sandy soils, sometimes, they are located in soils of calcareous sandy loam nature (Khabar, 2016). The existence of desert truffles is rarely noted in acid soils. It is interesting to point out that species of the genus *Helianthemum* are often symbiotic with desert truffles as *Helianthemum lipii* Pers., *H. hirtum* Mill, *H. asperum* Lag. Ex Dunal, *H. ledifolium* (L.) Mill. etc. The organic matter concentration, fertility, and exchange capability of soil must be low. Desert truffles need phosphate, nitrogen, potassium, calcium, and iron, yet it has been found that low levels of phosphate and iron enhance mycorrhizal potential. It should be noted that the mycorrhization potential is increased when phosphate and iron contents are low. The quantity and frequency of rainfall is a significant limiting factor for desert truffles in terms of climatic conditions. In general, rain is needed in the winter and spring months, but for some species, rain is needed both in the winter and spring. Desert truffles can be found in a variety of bioclimatic phases, including dry, semi-arid, sub-Saharan, and Saharan, based on just-released research. Despite being in a desert setting, the regions of Beni Guil and Abu Lakhal have the highest concentrations of desert truffles. 17.9 °C on average for the low and 18.6 °C on average for the high. As a result, these two places experience precipitation that is on average 170 millimetres per year. The development of truffles is greatly aided by the significant amounts of rainfall that fall in these regions throughout the night and early in the morning, as well as by dewfall, thunder, and lightning. The great desert and the bulk of these characteristics are found in southern Morocco (Bermaki *et al.*, 2017). In other parts of the globe, Saudi Arabia is conducting ecological research on desert truffles. Precipitation was listed by Hashem *et al.* (2018) as another essential element for the growth of the arid truffle. Reduced precipitation may change the host plant's physiological makeup and cause a decline in the production of spores and ascocarps. Additional factors include the weather, ambient temperature, and the physicochemical properties of the earth. The two main host plants on alkaline soils are *H. ledifolium* and *H. salicifolium* (L.) Mill. The reaping season starts in early December, and rain falls in October and December.

Truffle life cycle

In the context of defining the symbiotic view cycle of truffles, it is necessary to talk about the emergence and functioning of the mycorrhizal association. The fungi colonize the surfaces and the cortex. Externally, tiny fungal hyphae efficiently explore the soil. 90% of all plants depend on this symbiotic relationship, which differs in the anatomical structures, fungal taxa, and plant families involved (Brundrett, 2002; van der Heijden *et al*., 2015). The fossil record and phylogenetic analyses date the emergence of mycorrhizal communities to the Ordovician, where they played an important role in the colonizing of emerging terrestrial plants (Le Tacon and Selosse, 1994; Remy *et al*., 1994). Indeed, the fossil structure found is very similar to that of the arbuscular endomycorrhiza (AM) formed. Today, there are only 244 known species of Glomeromycetes with about 80% of all plants (Smith and Read, 2008). More recently, 100-200 Ma ago, ectomycorrhizal associations emerged (van der Heijden *et al*., 2015). This association concerns woody plants belonging to the families of Cistaceae, Pinaceae, Fagaceae, Tiliaceae, etc (Brundrett, 2002), which dominate the Mediterranean temperate and boreal forests (Smith and Read, 2008). The loss of genes is responsible for cellulose and lignin degradation (Plett and Martin, 2011). However, ectomycorrhizal fungi (ECMs) are endowed with a catalytic capacity to utilize soil organic and mineral matter (Rineau *et al*., 2012). It is crucial to note that, for instance, the truffle, can develop in pure culture using cellulose as a source of carbon (Mamoun and Olivier, 1991).

The truffles are ascomycetes with hypogeous fruiting that grow underground from 5 to 10 cm deep. Throughout the world, more than hundreds of different species of truffles are known, and regularly the discovery of new species is observed. Taxonomically, these mushrooms belong to the order *Pezizales* and the family Tuberaceae and Pezizaceae (El Enshasy *et al*., 2013). For centuries truffles belonging to the family *Tuberaceae* are widely edible, so the latter knew various lineages mainly truffle mushrooms (Læssøe and Hansen, 2007). Worldwide, the *Tuber* genus of the Tuberaceae family includes about 180 species (Bonito *et al*., 2010). The *Tuber* genus truffles that found in Europe's temperate forests, New Zealand, Australia, America and Asia are qualified as culinary quality (Kinoshita *et al*., 2011; Berch and Bonito, 2016). Generally, the desert truffles that grow in semi-arid and arid regions like Morocco, Egypt, Tunisia, Saudi Arabia, Syria, Kuwait, Iraq, and South Africa belong to the genus of *Tirmania* and *Terfezia* (El Enshasy *et al*., 2013, Bradai *et al*., 2015). *Tuber melanosporum*, *Tuber brumale*, *Tuber aestivum*, *Tuber indicum*, *Tuber uncinatum*, *Tuber himalayense*, and *Terfezia claveryi* are species of black truffles. Whereas, *Tuber magnatum*, *T. aculatum*, *T. borchii*, *T. latisporum*, *T. japonicum*, *T. oregonense*, and *Tirmania nivea* are the white truffles (Wang and Marcone, 2011). The Italian species (Eastern Europe) *T. magnatum* has been declared the most expensive truffle (Mello *et al*., 2006). Therefore, it is important to point out that, in the Italian markets, the price of one kilogram of this species is 8000 dollars (Jeandroz *et al*., 2008). Truffles are characterized by a genome with a large molecular weight; *T. melanosporum*, for example, has a 125 Mb genome (Chen *et al*., 2014).

Truffles are ectomycorrhizal fungus with symbiotic roots, characterized by a complicated life cycle, the mycelium establishing symbiotic connection with host species primarily with the roots of several trees, including *hazelnut*, *pine*, *poplar*, *oak*, and *eucalyptus* (Mello *et al*., 2006; Patel, 2012).

Since truffles grow their sexual fruiting bodies underground, insects and mammals are necessary for spore distribution (Læssøe and Hansen, 2007). The haploid spore develops into haploid free-living mycelium after ascospores have been released, creating an ectomycorrhizal connection with the roots of host plants. The ascoma-bearing asci, which is the sexual fruiting body, is then generated by the aggregation of hyphae (Figure 1) (Paolocci *et al*., 2006; Chen *et al*., 2019).

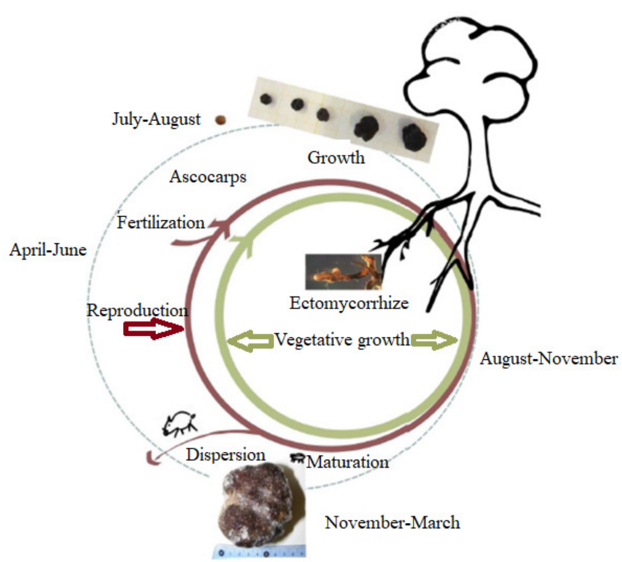

Figure 1. The annual life cycle of the truffle (Taschen, 2015)

For example, the cycle of life for truffles*, Tuber melanosporum* is a truffle fungus, the fruiting of this species is localized in open woodlands. During the vegetative phase, the formation of mycelium in the soil is seen, developing ectomycorrhizal relationships with many plant groupings (Figure 1). Its most well-known host species mainly for inoculation are *oaks* (*Quercus* spp., Fagaceae) and hazels (*Corylus* spp., Betulaceae) (Olivier *et al*., 2012). According to Comandini *et al*. (2006), *Cistus* are fewer known hosts for the presence of truffle species or the genus *Tuber*, or *arbutus*; (a species of small tree shrubs of the family Ericaceae) (Lancellotti *et al*., 2014). It is, therefore, necessary to point out that, the burnt is an important indicator of the presence of mycelium of truffles in the ground (Streiblová *et al*., 2012). It is most observable in spring. In some places, few or no burns are visible, but the name always refers to the area where the truffle grows. When these burnt areas are productive, the fruiting of the truffle ascomycetes begins in spring, we speak of a period known as birth that can last until the end of July (Kulifaj, 1984). After a few months, the development and enlargement of the ascocarp are in the soil releasing a particular aroma (sulfur compounds such as dimethyl sulfide and alcohols such as 2-methyl1-propanol and 1-octen-3-ol (Splivallo *et al*., 2011). From November until the first frosts in the soil, it reaches its sporal and aromatic maturity.

Considerations of biochemistry and physiology

The desert truffles have a distinctive economic and medicinal significance and are extensively used throughout the globe. Polysaccharides have been found to be present in medicinal mushrooms, and these polysaccharides have been shown to have antibacterial and anticancer properties (Schillaci *et al.*, 2017). Rare reports on the chemistry and makeup of truffles, which frequently represent their economic importance, are extremely rare. Truffles are a fantastic and plentiful supply of carbs, fiber, high-quality protein, and amino acids (Murcia *et al.*, 2003; Mandeel and Al-Laith, 2007). According to estimates, proteins make up 20% of the dry bulk of desert truffles, which is more than the majority of plants and fungi. Desert truffles are also frequently suggested for their therapeutic benefits against a variety of diseases (Murcia *et al*., 2003; El Enshasy *et al*., 2013). Additionally, truffles are a particularly abundant source of a number of chemical compounds with clinically significant anti-inflammatory, antimutagenic, antibacterial, and anticarcinogenic properties (Murcia *et al.*, 2002; Al-Laith, 2010; Dib-Bellahouel and Fortas, 2011). Truffles are also said to have anti-inflammatory and antioxidant qualities (Murcia *et al.*, 2002; Kagan-Zur *et al.*, 2013).

Truffles contain bioactive organic components like ergosterol, phenolic acids, carotenoids, flavonoids, and phenolic derivatives, which account for their antioxidant activity (Al-Laith, 2010; Villares *et al*., 2012). In a separate study, Bouzadi *et al*. (2017) determined the protein (16.3% and 18.5%), fat (6.2 and 5.9%), and carbohydrate (67.2 and 65%) content of Libyan wild truffle (*Terfezia* and *tirmania*). Other studies indicate that *Terfezia* and *Tirmania* ascocarps (fruiting bodies), which are found in desert truffles, are well-known delicacy that are heavily promoted primarily for their flavour and nutritive value (Kagan-Zur *et al*., 2014). Thus, *Terfezia boudieri* contains saturated and unsaturated fatty acids, such as behenic, stearic, margaric, pentadecanoic, arachidic, palmitoleic, palmitic, stearic, oleic, linoleic, and linolenic, according to Bokhary *et al*. (1989) and Bouzadi *et al*. (2017) also reported an abundance of potassium, iron, proteins and phenolics in (black truffle) *Terfezia claveryi* and *Tirmania nivea* (white truffle). Numerous researchers, like Chellal and Lukasova (1995), Janakat *et al*. (2004) and Janakat *et al*. (2005), have established the therapeutic qualities of desert truffles, including their antibacterial and antimicrobial properties. Splivallo (2008) about two hundred different secondary metabolites have been found in truffles, including terpenoids, flavonoids, fatty acids, essential oils, phenolics and aromatic chemicals, the dry biomass of Iraqi truffles (*Tirmania pinoyi, Terfezia claveryi* and *Tirmania nivea*) contains 9.7 and 25.5% phosphorus, 8.1% to 13.8% protein and 16.6% to 24.8% carbohydrates, as described by (Hussain and Al-Ruqaie, 1999). Also included in truffles are the important minerals K, Na, Ca, Al, Zn, Mn, and Mg (Wang and Marcone, 2011). Furthermore, up to 80% of truffle biomass is comprised of insoluble polysaccharides, hemicelluloses, chitin and pectin (Cheung, 1997). Desert truffles also contained bioactive substances such as phenols, anthocyanin and carotenoids (Gouzi *et al*., 2013). In addition to noticing that the desert truffle fruiting bodies contain a significant quantity of sugar (15.4%), Slama *et al*. (2009) noted that only 2.02% of the various individual sugars determined are soluble and the remaining 10.5% are insoluble. Truffles from the desert are rich in calcium, potassium, phosphorus, magnesium and iron. For instance, *Terfezia boudieri* provides adequate levels of potassium, calcium, phosphorus, and magnesium. Truffles found in the desert typically have higher calcium content than black and white truffles (*Tuber melanosporum* and *Tuber magnatum*). To have a clear understanding of the desert truffles present in Morocco, a detailed study will be necessary. All of these facts, however, make desert truffles an intriguing topic for future researchers of these valuable fungus. It's important to note that a study the general and spore-related aspects of *Terfezia claveryi*, including germination and spore quantity (Al-Sheikh and Trappe, 1990). On modified Melin-Norkrans agar medium and potato dextrose media, desert truffle mycelia grew best at neutral pH, suggesting its potential use for the productive and effective creation (generation) and cultivation of desert truffles for commercial purposes (Morte *et al*., 1994; Morte and Honrubia, 1995; Morte and Honrubia, 1997). There are several stringent laboratory and physio-biochemical conditions for good desert growth and productivity. Pérez-Gilabert *et al*. (2001) described the characterization and biochemical properties of the inactive *Terfezia claveryi*. Due to the fact that desert truffles can grow under circumstances of water stress, several studies have examined the effects of polyethylene glycol induced osmotic stress on two desert truffles (Mexal and Reid, 1973; Coleman *et al*., 1989; Navarro-Ródenas *et al*., 2011). According to Navarro-Ródenas *et al*. (2011) who discovered that it increased under dry conditions, alkaline phosphatase (ALP) activity is a major indicator of the metabolic activity of these fungi. They found that *Terfezia claveryi* strain TcS2 and *Picoa lefebvrei* strain OL2 are two species of desert truffles that have been demonstrated to be able to withstand water stress at pressures lower than 1.07MPa. Even the formation of mycelial inoculum in these arid truffles was found to be enhanced by water stress. According to Akyüz *et al*. (2012) *Terfezia boudieri* arid truffles have medicinal uses and contain phenolic compounds, antioxidants and other minerals.

Mycorrhizal association of truffles

Desert truffles are culinary mushrooms that require plant roots as a living environment in order to thrive. In addition to the significant nutrients they contain, they also contain a high concentration of therapeutically beneficial secondary metabolites (Zniber *et al*., 2022). There are approximately 10 species that may be found in the semiarid and arid climate zones of Morocco, which are characterised by low yearly rainfall and high average temperatures (Zniber *et al*., 2022). They may be related to the *Cistus* and *Pinus* species as well as a few other species, but they are most frequently found with the *Helianthemum* species (Zniber et *al.*, 2022). In the same sense, a group of edible hypogeous fungus known as desert truffles that create mycorrhizal symbiosis with perennial and annual plants shrubs from plant family *Cistaceae*, which is adapted to arid and semi-arid regions (Kovács and Trappe, 2013; Roth-Bejerano *et al*., 2014). These areas are recognised by an aridity index AI 0.5, which is the proportion between yearly precipitation and interest evapotranspiration, as well as by poorly fertile soils with a sandy texture and low inputs of organic substances, according to the United Nations Educational, Scientific, Cultural Organization (1979) and Bonifacio and Morte (2014). Additionally, desert truffles interact with a mutualistic partner with mycorrhizal fungi and exist in symbiosis with plants. According to several studies by Díez *et al*. (2002), Mandeel and Al-Laith (2007) desert truffles in Algeria's Sahara region have symbiotic relationships with *Helianthemum lippii*. The hypogeous ascomycetes develop mycorrhizal associations that share mutualistic relationships with several species of *Helianthemum* roots, according to (Mandeel and Al-Laith, 2007; Kagan-Zur *et al*., 2014). Another study cites that Mutualistic symbionts help their host plants develop and survive in certain environment conditions (Morte *et al*., 2010). For instance, *Terfezia claveryi* mycorrhizas stimulate the assimilation of phosphorus, nitrogen and potassium in *Helianthemum almeriense*, which increases the plant's survival during droughts (Morte *et al*., 2000). Because of this interaction, the expression of plant and fungal aquaporins as well as the amount of hydrogen peroxide in roots are finely regulated (Navarro-Ródenas *et al*., 2013; Marqués-Gálvez *et al*., 2020). Several *Terfezia* species, including *T. boudieri* and *T. claveryi*, as well as *Tirmania* species, including *T. Nivea* and *T. pinoyi*, have been found to have mycorrhizal associations with *Helianthemum lippii*. They also form advantageous mycorrhizal connections with *Helianthemum* species like *H. ledifolium and H. salicifolium* (Awameh and Alsheikh, 1980; Kovács and Trappe, 2013). *Helianthemum* species form both ectomycorrhizal and ecto-endomycorrhizal connections (Claridge *et al*., 2013). Although these species have been observed to lack a Hartig net and their mantle in the roots of the endomycorrhizal desert truffles, they still display undifferentiated hyphae, as seen, for example, in associations between *Helianthemum spp*. and a number of species of *Terfezia* and *Tirmania* (Dexheimer *et al.*, 1985). Thus, it is very important to mention that ectendomycorrhiza is the name for the kind of mycorrhiza created by these fungi (EEM). EEMs have a thin, disorganised fungal mantle covering the colonised roots, intercellular Hartig nets, intracellular hyphas that enter cortical cells and create coil-like structures, and all of these features (Morte *et al*., 1994; Yu *et al*., 2001). Intercellular or intracellular mycorrhizal structures can rely on a variety of factors, according to another relatively recent study. In field conditions, low auxin, low phosphate, and/or low water availability favour the intracellular mycorrhizal form, while in vitro, high auxin, phosphate, and/or water concentrations favour the intercellular mycorrhizal form (Navarro-Ródenas *et al*., 2012; Gutiérrez *et al*., 2003; Zaretsky *et al*., 2006). Due to this, it is possible to consider desert truffles as a type of intermediary connection between real ecto and endomycorrhizal interactions. But the division between these two typical mycorrhizal connections is crystalline and fluid at the same time. It should be noted that the traits and characteristics of mycorrhizal relationships are usually and frequently determined by both internal and external factors. The ability of mycorrhizal associations to endure some degree of harsh environmental conditions is superior to plants in dry and semiarid areas of the world (Morte *et al.*, 2009). A few varieties of truffle, including *Terfezia claveryi* and *Picoa lefebvrei* (*Phalangium lefebvrei*), are hypogeous ascomycetes that thrive in semiarid climates on marl and gypsum rich soils. Additionally, these species establish mycorrhizal connections with the bulk of perennial and annual *Helianthemum* species (Honrubia *et al.*, 1992). An ectomycorrhizal link exists between *Helianthemum ovatum* and *Helianthemirhiza hirsuta* (Kovács *et al.*, 2011). This specific association has a simple mycorrhizal system with borders that are often cottony, straight or slightly curved, bending, or tortuous, and vary in colour from ochre to brown. A thorough investigation into desert truffles and their interactions with different plants was carried out by (Kovacs *et al.*, 2002). The interaction with plants and ensuing behaviour of both partners under aseptic conditions were investigated using modified Melin-Norkrans (MMN) substrates enriched with various phosphate concentrations. In order to assess the changes caused by *Terfezia terfezioides* interaction with *Robinia pseudoacacia* and *Helianthemum ovatum*, this task was carried out. Black locust colonisation has frequently stayed delicate and weaker than the *Helianthemum's* root system. Only in *Helianthemum* do the intercellular hyphae usually create a Hartig net with such finger like structures; without prior clear evidence, these kinds of contacts could not be classified as mycorrhizae. This is one of the few essential characteristics. They also observed that the RFLP profiles of the nuclear DNA ITS of 19 fungal fruiting bodies that had been concurrently collected from the same habitat showed no appreciable variation. They also showed that the three randomly selected specimens' ITS sequences shared similarities. The inconsistency between these types emphasizes the necessity for the creation and design of species-specific PCR primers, which could play a significant role in clearly identifying the host plants. A mycorrhizal relationship was created by *Helianthemum almeriense* Pau, *Terfezia claveryi* and *Picoa lefebvrei.* In their important, thorough review of the mycorrhizal associations of desert truffles with the genus *Helianthemum*, Gutierrez *et al.* (2004) examined the morphological traits of this association. Additionally, they discussed the structure and ultrastructure of the established mycorrhizae of this plant species with *Terfezia claveryi* and *Picoa lefebvrei* as well as the morphology of the mycorrhizal associations in which *Helianthemum almeriense* is one of the partners. To further investigate the fungal inocula and mycorrhizal connections with plants and subsequent plantations, a knowledge of the use of biotechnological tools and management methods has been developed and introduced for a select few *Terfezia* species. According to Morte and Honrubia (1997) agar or modified Melin-Norkrans (MMN) inocula can be used straight from the plates as inocula for the creation and synthesis of in vitro mycorrhization". Since they are mycorrhizal, true *Terfezia* species have been used in mycorrhizal bioassay tests with plants, mainly from the genus *Helianthemum* (Kovács *et al*., 2002). They thoroughly examined the truffle's anatomy and ultrastructure, and they investigated *Terfezia terfezioides*' relationships with *Robinia pseudoacacia* and Helianthemum *ovatum in vitro*. Morte *et al*. (2008) carried out a comparable study based on the techniques employed in the efficient synthesis of mycorrhiza between desert truffles and *Helianthemum* species. Agar or modified Melin-Norkrans (MMN) media can be used to make inocula, according to Morte *et al*. (1994) and Morte and Honrubia (1997). According to the source of the fungal inocula (whether it be from spores or mycelia), the source of the plant (whether it be seedlings or micro propagated plantlets), and the culture conditions, Morte *et al*. (2008) conducted a similar investigation into the processes involved in the efficient synthesis of mycorrhiza between *Helianthemum* species and desert truffles. Khanaqa (2006) different research, suggested cultivating desert truffles in plantations with Olea europaea, which would have a double beneficial effect. The tree will increase water retention, lessen soil erosion, and enhance soil fertility. According to Lopez Nicolás *et al*. (2013), the compound -cyclodextrin was effective at encouraging the mycelial growth of *T. claveryi*. It was discovered that the dominant sunflower species in Libya, *Helianthemum kahiricum* and *Helianthemum lippii*, developed mycorrhiza with arid truffles (Bouzadi *et al*., 2017). Mycorrhizal connections can be formed by the majority of desert truffles, but *Terfezia claveryi* and *Picoa lefebvrei* are the two most frequently cited candidates for this particular quality. to improve farming, ecological, and biotechnological practises in dry and desert landscapes implementing mycorrhizal technology could prove to be a crucial component in Saudi Arabia's improvement of many arid plants. This area needs to be carefully and thoroughly explored.

Conclusions

Desert truffles are both highly valuable commercially and highly beneficial medically. However, further study is still needed to better our understanding of the taxonomy of desert truffles and to conduct in-depth analyses of their biochemical and medicinal properties. Both molecular and morphological methods should be used for this study. A potent technique, in vitro mycorrhization also has positive effects on Morocco's conservation of truffle biodiversity. It might boost these indicators as well as the development, production, and overall calibre of desert truffles. The precise taxonomic delimitation of truffles using conventional and molecular technologies, as well as their bioprospecting via biotechnological interventions, have attained special importance because of the high market value and financial benefits that truffles offer.

Given the importance of truffles we have fixed the main objective of this scientific review is to optimize the cultivation conditions of some southeastern truffles in Morocco based on mycorrhization. To achieve this objective, we first presented a brief bibliographic analysis of the geographical distribution of desert truffles throughout the world, particularly in Morocco, including their biology, ecology, host plants, chemical compositions, and mycorrhizal association.

Authors' Contributions

KH, OL and TA Conceptualization KH, OL and TA writing original draft; KH, OL and TA writing, review and editing.

All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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