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Desert truffles of the North Algerian Sahara: Diversity and bioecology

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Abstract

This study reports on the bio-ecology of desert truffles collected from the Northern Algerian Sahara. It aims focused on (i) the identification of desert truffle species with a morphometric characterization, (ii) the determination of their geographical distribution, and (iii) the description of the edaphic, climatic and geomorphological characteristics of their natural habitat. The harvest of 78 truffle fruiting bodies from seven different locations resulted in the identification of three species of the family Pezizaceae: *Terfezia arenaria* (Moris) Trappe, *Terfezia claveryi* Chatin and *Tirmania nivea* (Desf.) Trappe. These hypogeous ascomycetes live in mycorrhizal association with *Helianthemum lippii* (Cistaceae). Desert truffles grow in heterogeneous soils of sandy texture, moderately calcareous (10.19 ± 1.37%), slightly alkaline (7.87 ± 0.22), with low organic matter (0.86 ± 0.1%) and slight phosphorus contents. The development of desert truffles is closely linked with high rainfall occurring during fall and/or winter. The truffles colonize desert depressions "Dayas" and beds of Wadis, since these geomorphological zones accumulate rainwater, which promotes the growth of both truffles and its host–plant.

Key words: Algerian Sahara, Biodiversity, Bioecology, Desert truffles, Mycorrhizae, Terfeziaceae

Introduction

Desert truffles are hypogeous ascomycetes in Mediterranean countries consisting of genera such as *Terfezia*, *Delastria*, *Mattirolomyces*, *Picoa*, and *Tirmania* (Trappe, 1979; Kovács and Trappe, 2014). From their name, desert truffles include species typically distributed in regions with arid and semi-arid climates (Honrubia et al., 1992). These truffle species have developed adaptations to exploit various types of soil of various characteristics, particularly in association with plant species of the family Cistaceae, mainly the genus *Helianthemum* (Malençon, 1973; Alsheikh and Trappe, 1983; Chevalier et al., 1984; Alsheikh, 1985; Kagan-Zur et al., 1994, 1999; Khabar et al., 2001; Slama et al., 2006; Kovács et al., 2007).

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Besides their wide distribution, the order Pezizales predominates in arid and semi-arid regions of the Mediterranean basin and adjacent areas, including North Africa (Malençon, 1973; Trappe, 1979; Khabar et al., 2001; Slama et al., 2006), the Middle East (Al-Ruqaie, 2002; Mandeel and Al-Laith, 2007), Southern Europe (Janex-Favre et al., 1988; Honrubia et al., 1992; Ławrynowicz et al., 1997; Moreno et al., 2002) and also the Kalahari Desert (Díez et al., 2002; Mandeel and Al-Laith, 2007; Trappe et al., 2008a, 2014b). In the Mediterranean regions, *Terfezia* and *Tirmania* spp. form mycorrhizal associations mainly on roots of various species of the genus *Helianthemum* Miller (Dexheimer et al., 1985; Fortas and Chevalier, 1992; Gücin and Dülger, 1997). Other genera of desert truffles occur in Africa, Australia and North America (Kovács and Trappe, 2014).

In Algeria, research on desert truffles is sparse, especially in the Sahara desert. Although existing reports described a few species of the genera *Terfezia* and *Tirmania*, they performed mycorrhization tests on desert truffles with other plants in addition to *Helianthemum* spp. All documented studies mainly focus either on the steppe regions (Bessah, 1999), or approached the

Occidental Sahara of Algeria (Fortas, 1990; Tadja, 1996). Therefore the importance and benefits of these symbiotic fungi remain unknown in the Sahara Desert, which represents the most hostile ecoregion worldwide. Furthermore, the current study focuses on identification and morphological characterization of edible species of desert truffles found in Northern Algerian Sahara in relation with their distributional habitats. This pioneer study aims to provide information about species bio-ecology including the geographical distribution, habitat description, species occurrence frequency, main edaphic and climatic factors controlling their distribution and occurrence.

Materials and Methods

Study area

The study area is located in province “Wilaya” of Ghardaia and Ouargla in the Northern Sahara (Algeria), covering an area of 200,000 km², between 28°40'N to 33°40'N and 02°00'E to 08°00'E (Figure 1). The study was conducted during January to March of 2006 to 2012.

The climate is typically hot-arid. Average temperatures are high, with absolute maxima in July–August exceeding 50 °C, and minima in January ranging from 2 to 9 °C (Le Houerou, 1990). Soil surface temperature may exceed 70 °C; however, the temperature rapidly deceases with depth. Because of low cloudiness, the sunlight in the Sahara Desert is relatively strong and has a drying effect by raising the temperature (Ozenda, 2004). Practically, precipitation always occurs as rain characterized by its slight importance; torrential rains are rare. Rains are related to Sudano-Saharan and Saharan meteorological disturbances (Dubief, 1963). Such insufficient Saharan rains are associated with a significant irregularity of rainfall patterns and a considerable interannual variability, which induce more or less lengthy severe droughts (Ozenda, 2004).

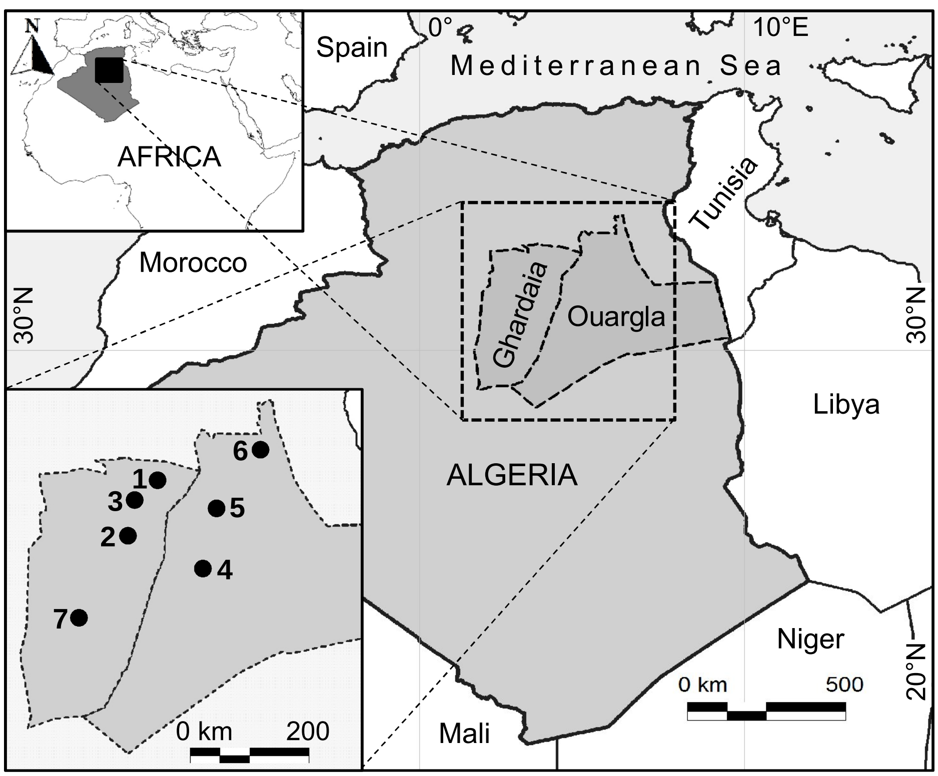

Figure 1. Location of the surveyed area in Northern Algerian Sahara. The study area includes Ghardaia and Ouargla spotted inside the dashed square. Solid dots (●) represent location of the seven sampling sites: 1: Guerrara, 2: Hassi El Fehal, 3: Noumrate, 4: Oued M’ya, 5: Oued N’ssa, 6: Stah El Merdfa, 7: Golea.

Choice of sampling sites

Seven sampling sites were chosen inside the study area for the collection and harvest of desert truffles. Site selection was based on the guidance of local inhabitants and nomads of the Sahara Desert. Seekers of desert truffles, "Truffle hunters" were also consulted. The selected sites were known to be usual producing areas of desert truffles.

Within each sampling site, a station of one hectare area (100 × 100 m) was delineated. The choice of all stations was based on the use of a purposeful sampling by choosing stations which looked particularly homogeneous and representative (Gounot, 1969).

In the vicinity of host plants in the genus *Helianthemum* (Alsheikh, 1985), the desert truffles were detected *in situ* by observing cracks and swellings in soil surfaces caused by emergence of the ascocarps (Figure 2).

Morphological study of Truffles

By use of a stereo zoom binocular microscope, morphology of macroscopic characters, in particular the shape and colour, was described for each part of the truffle, namely the ascocarp, the peridium and the gleba. To identify and characterize the species harvested, fresh samples were cut with a sharp blade, placed in 5% KOH, and stained with Melzer's reagent. Various characteristics such as ascospore shape, number per ascus, colour and orientation were observed under an optical microscope (magnification ×100) connected to a computer for species recognition. The dimensions of the asci and ascospores were measured using the Bio microscopic software “Motic Image Plus 2.0”. Truffle species were identified by available keys such as Trappe (1979) and Ferdman et al. (2005).

Soil sampling and analysis

At each truffle harvest point, a soil sample was collected at a depth of about 10–25 cm. Soil samples were dried in open air in the laboratory at ± 25°C, sieved through a 2 mm sieve and analysed to determine the physicochemical characteristics by standard methods (Baize, 2000).

The analysed soil parameters were particle size, determined by the international method “Robison’s pipette”; electrical conductivity “EC” was measured with a conductivity-meter at 25°C on a soil:water ratio of 1:5, then the concentration of salts "salinity" was calculated by this formula: soil salinity in mg/L = 640 × EC in dS/m (Baize, 2000); pH was determined with a pH-meter with glass electrode on a soil:water ratio equal to 1:5; total $CaCO_3$ was measured by Bernard calcimeter; organic matter was identified by Anne’s method (AFNOR, 1996); HCO^{3-} was determined by titration with H_2SO_4 and SO_4^{2-} by the gravimetric method after precipitation as barium chloride (AFNOR, 1996); phosphorus, Ca^{++}, Mg^{++} and K^+ were determined by an atomic absorption spectrophotometer on a soil:water extract ratio of 1:5 (Baize, 2000).

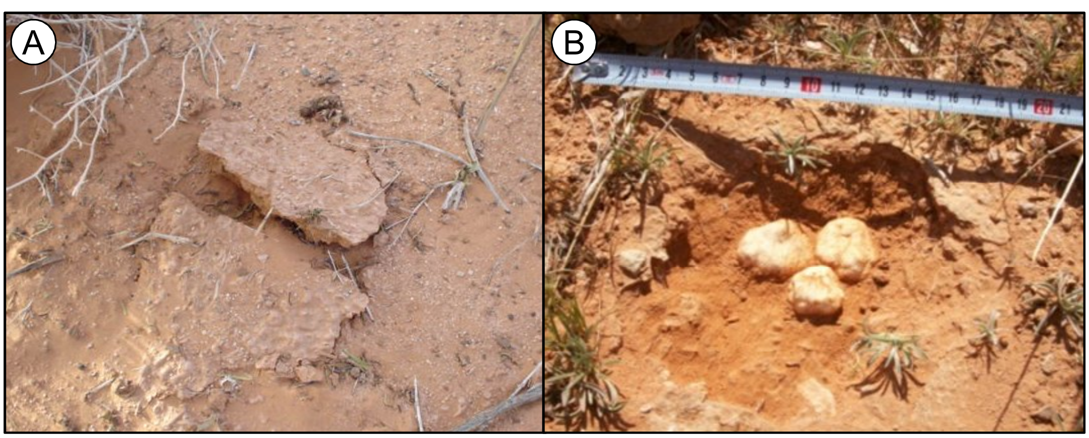

Figure 2. General view of the collection points of desert truffles (A: Swelling of the ground caused by Truffle, B: View of *Tirmania nivea* growing deep in the earth and the surrounding vegetation, including young seedlings of *Helianthemum lippii*).

Statistical analysis

A Pearson's Chi-square test (χ^2) was performed to test the null hypothesis that no association exists between the occurrence of desert truffle species and the study sites.

Means and standard deviations of soil factors were given for each site. After assessing the normal distribution and homogeneity of data by the Shapiro-Wilk normality test, all soil parameters were tested for significant differences between sampled sites using One-Way ANOVA followed by Tukey's post hoc test when the test is positive. R-commander {Rcmdr} was used as a statistical package for computations (Fox, 2005).

Results and Discussions

Identification and distribution of truffle species

Following the sampling of seven sites at the Northern Algerian Sahara during the period 2006 to 2012, a total of 78 fresh fruiting bodies of truffles were collected. The harvested desert truffles belonged to *Terfezia* or *Tirmania* (Pezizaceae) and three species: *Terfezia arenaria*, locally called in Arabic "Terfesse Lahmar", *Terfezia claveryi*, known vernacularly as "Terfesse Lakhal" and *Tirmania nivea*, commonly called "Terfesse Labyadh".

The most abundant species over all sampled sites was *Tirmania nivea* with a mean relative abundance of 70 ± 10.1%, followed by *Terfezia arenaria* whose occurrence ranged from 19 to 37% (mean = 22.9 ± 8.1%). *Terfezia claveryi* occurred r between 0 and 17% with an average of 9.9 ± 5% (Figure 3). According to Pearson's Chi-square test, no significant relationship was found between number of harvested fruiting bodies of each truffle species and the sampled sites (χ^2 = 11.01, *df* = 12, *P* = 0.528).

Desert truffles are limited to semi-arid and arid areas, especially in countries of the Mediterranean basin, including Southern Europe as Portugal, Spain, France, Italy, Hungary and Turkey (Janex-Favre et al., 1988; Honrubia et al., 1992; Moreno et al., 2002), and North Africa, extending from Morocco to Egypt (Malençon, 1973; Bokhary, 1987; Khabar et al., 2001), and the Middle East (Alsheikh and Trappe, 1983; Alsheikh, 1985; Mandeel and Al-Laith, 2007). Some species of desert truffles also occur in Botswana, Namibia, and South Africa (Marasas and Trappe, 1973; Trappe et al., 2008a, 2014a), Australia (Trappe et al., 2008b, 2010, Claridge et al., 2014), and Mexico and the USA of North America (Moreno et al. 2012, Trappe et al. 2014b).

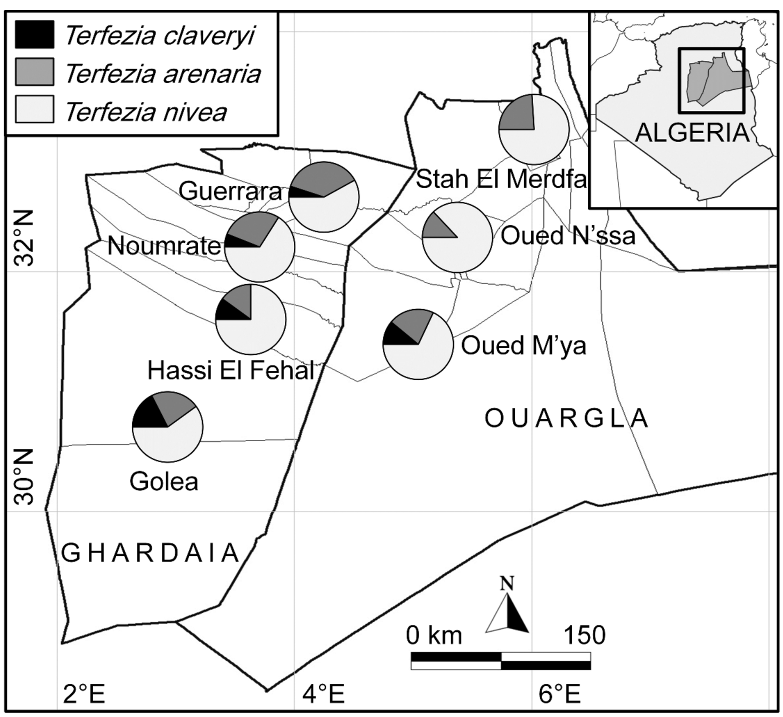

Figure 3. Distribution and density of desert truffles in the Northern Algerian Sahara. (Charts represent occurrence frequencies of the surveyed truffle species within each site).

Morphometric description of surveyed truffles

The macroscopic and microscopic characters and anatomy of the fruiting body for the identified truffle species are detailed in Figure 4.

• ***Terfezia arenaria*** — **Ascocarps**: subglobular to tuberiform, 7 – 12 cm in diameter, with peduncle at the base. The colour ranges from dark-brown to brown (Figure 4A). **Peridium**: brownish, 0.75 – 2 mm thick with a smooth, often cracked surface (Figure 4B). **Gleba**: fleshy, mottled reddish to pinkish, with visible sterile veins irregularly delineating the fertile areas. **Asci**: subglobose, sometimes ovoid, randomly arranged in fungal tissues, 62–71 × 73–83 μm in diameter. At maturity it contains six ascospores. **Ascospores**: yellowish, thin-walled hyaline, freely placed inside asci, with spherical shape and size ranging from 21–25 × 22–23 μm (Figure 4C).

• ***Terfezia claveryi*** — **Ascocarps**: measuring 5–8 cm in diameter, sub-globular sometimes pyriform, gibbous sterile surface, pale-brown to brown, tinted blackish-brown at maturity (Figure 4D). **Peridium**: orange-brown coloured, 0.8–1.2 mm thick (Figure 4E). **Gleba**: fleshy, compact, first yellowish then reddish at maturity, divided by pale veins. **Asci**: globose, 73–93 × 62–74 μm, contain eight spores. **Ascospores**: yellowish, arranged randomly in hyphae tissue at maturity, globose, 17 – 22 μm broad (Figure 4F).

• ***Tirmania nivea*** — **Ascocarps**: often subglobose or lobed pyriform, short and smooth pedicel, can reach 4–8 cm in diameter, whitish cream-coloured to white (Figure 4G). **Peridium**: 1.5–2 mm thick, yellowish milky white (Figure 4H). **Gleba**: fleshy white, solid, slightly marbled with some veins of 1.8–4.9 mm wide. **Asci**: ellipsoid to obovoid, 56–73 × 38–47 μm, amyloid, most with eight hyaline spores with short pedicel. **Ascospores**: bluish, thin-walled, freely arranged within the asci, ellipsoid, 15–18 × 11–13.5 μm (Figure 4I).

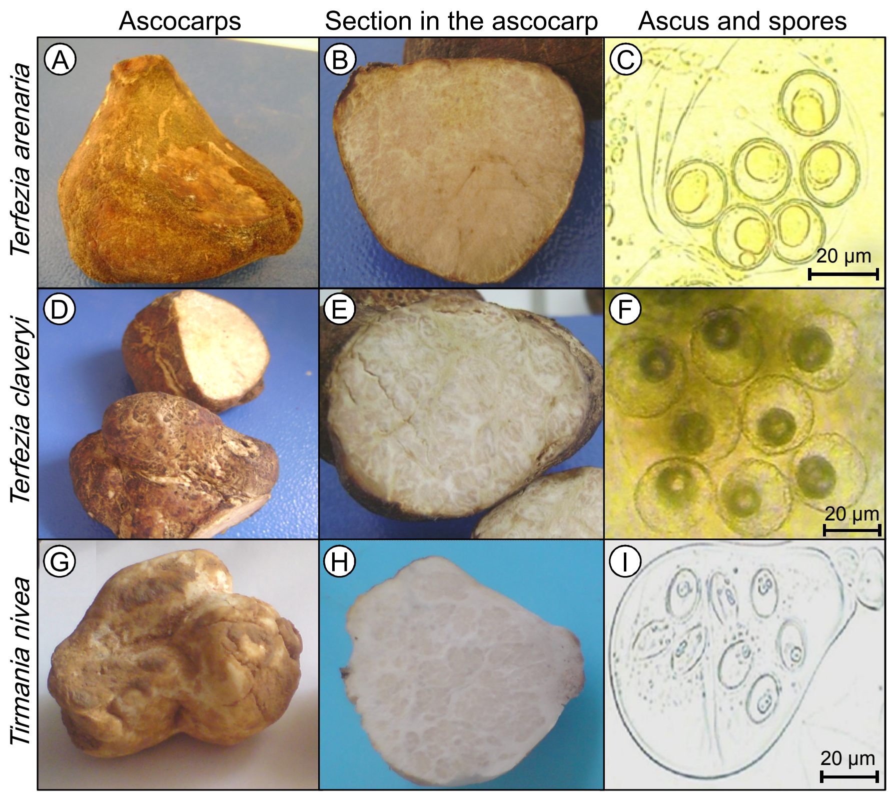

Figure 4. An overview of some morphometric and anatomical characteristics of fruiting bodies of *Terfezia arenaria* (A: Ascocarp, B: section of ascocarp, and C: ascus with and six ascospores), *Terfezia claveryi* (D: Ascocarp, E: ascocarp section, and F: ascospores) and *Tirmania nivea* (G: Ascocarp, H: cross section of ascocarp, and I: ascus with and eight ascospores) collected from the Northern Algerian Sahara Desert.

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The morphological and anatomical characteristics of *Terfezia arenaria*, *Terfezia claveryi*, and *Tirmania nivea* found in the study area are in ideal agreement with descriptions of the same truffle species of Africa (Malençon, 1973; Khabar et al., 2001; Slama et al., 2006), those of Kuwait (Alsheikh and Trappe, 1983), Saudi Arabia (Bokhary, 1987), Irak (Abd-Allah et al., 1989), Egypt (El-Kholy, 1989), Mediterranean Basin (Morte et al., 2009), and at world scale (Trappe, 1979).

Bioecology of desert truffles

Edaphic parameters

Results of the physicochemical analyses applied for soil samples extracted from different parts of the North Algerian Sahara are shown in Table 1.

Soil analyses of sites producing desert truffles showed wide heterogeneous pedological characteristics between the sites. Indeed, ANOVA tests showed a significant variation ($P < 0.001$) in values of most edaphic factors (except K^+ and $SO_4^=$) between the sampled sites. Tukey's post hoc showed that these sites belong to different classes (2–7 groups, following soil factors) which support the finding on heterogeneous pattern of desert truffles distribution over the Northern Algerian Sahara, where truffles recorded different occurrence frequencies within each site.

Despite this inter-site differences, the grain size analysis, based on the American classification of soil textures (Eswaran et al., 2010), showed that all habitats of truffles in the Northern Sahara have soils of sandy texture and single grained structure, where sand grains have high rates of 80.6–91.7%.

Chemically, the habitats of desert truffles were characterized by soils having slightly alkaline pH (Baize, 2000) whose values varied slightly between 7.60 and 8.05. According to the classification scale of salinity of the 1:5 aqueous extract (Aubert, 1978), the sampled soils possess salinity degrees less than 100 mg/L because electrical conductivity values were slight and varied between 0.65 and 0.79 dS/m, which indicates non-saline soils. The content of organic matter ranged from 0.78 to 0.98%. These values reveal a high deficient in soil organic matter according to the scale of organic matter defined by Morond (2001). In addition, the contents of $CaCO_3$ varied from 9.09 to 12.01%, revealing that the sampled soils were moderately calcareous following the scale of total $CaCO_3$. The phosphorus content ranged between 23.42 and 25.54 ppm, indicating soils are poor in phosphorus (Baize, 2000).

Table 1. Means (± standard deviation) of physico-chemical soil analyses carried out at sites of harvesting desert truffles in the Northern Sahara of Algeria. Outcomes of One-way ANOVA test are given as *F* (*df* between groups, *df* within groups) and *P*-value. Letters show significant differences between sites according to Tukey's post hoc test (95% family-wise confidence level): Tukey (HSD) critical value = 3.027. (EC: electrical conductivity, n: number of soil samples analysed in each site).

Soil parameter	Sampled sites (n = 78)							ANOVA	
	Guerrara (n = 10)	Hassi El Fehal (n = 7)	Noumrate (n = 15)	Oued M'ya (n = 17)	Oued N'ssa (n = 11)	Stah El Merdfa (n = 10)	Golea (n = 8)	$F_{(6, 71)}$	P
Clay (%)	2.38 ± 0.18^{a}	2.07 ± 0.19^{b}	0.18 ± 0.04^{c}	1.64 ± 0.29^{d}	2.69 ± 0.25^{e}	3.19 ± 0.12^{f}	2.05 ± 0.08^{b}	316.57	<0.001
Silt (%)	13.9 ± 2.18^{a}	6.2 ± 1.38^{b}	18.03 ± 0.49^{c}	9.66 ± 6.52^{b}	16.72 ± 0.7^{ac}	15.29 ± 0.89^{ac}	6.98 ± 0.61^{b}	20.84	<0.001
Sand (%)	83.72 ± 2.25^{a}	91.73 ± 1.24^{b}	81.79 ± 0.51^{a}	88.67 ± 6.53^{b}	80.6 ± 0.78^{a}	81.53 ± 0.94^{a}	90.97 ± 0.62^{b}	19.74	<0.001
EC (dS/m)	0.66 ± 0.04^{a}	0.66 ± 0.06^{a}	0.79 ± 0.07^{a}	0.78 ± 0.07^{a}	0.67 ± 0.03^{a}	0.78 ± 0.08^{b}	0.65 ± 0.07^{a}	11.63	<0.001
pH	7.88 ± 0.12^{ab}	7.78 ± 0.39^{ac}	7.96 ± 0.07^{b}	8.05 ± 0.11^{b}	7.60 ± 0.21^{c}	7.90 ± 0.07^{ab}	7.84 ± 0.1^{bc}	10.62	<0.001
Total $CaCO_3$ (%)	10.21 ± 0.76^{ab}	11.28 ± 1.26^{ac}	11.66 ± 1.13^{c}	9.09 ± 0.54^{d}	9.19 ± 0.32^{bd}	9.09 ± 0.77^{d}	12.01 ± 0.11^{c}	27.09	<0.001
Organic matter (%)	0.83 ± 0.11^{ab}	0.83 ± 0.05^{bc}	0.85 ± 0.04^{ab}	0.84 ± 0.08^{ab}	0.78 ± 0.07^{b}	0.97 ± 0.09^{c}	0.98 ± 0.1^{ac}	6.42	<0.001
Phosphorus (ppm)	22.09 ± 1.32^{a}	23.42 ± 1.38^{ab}	21.95 ± 1.09^{a}	24.22 ± 1.05^{b}	21.83 ± 1.50^{a}	22.28 ± 0.94^{a}	25.54 ± 0.50^{c}	14.83	<0.001
Ca^{++} ($cmol^+$/kg)	6.26 ± 0.17^{a}	5.19 ± 0.49^{b}	6.26 ± 0.17^{a}	4.62 ± 0.7^{c}	5.31 ± 0.08^{b}	4 ± 0.46^{d}	5.02 ± 0.12^{bc}	42.70	<0.001
Mg^{++} ($cmol^+$/kg)	1.44 ± 0.19^{ab}	1.13 ± 0.13^{c}	1.28 ± 0.2^{ac}	1.46 ± 0.1^{b}	1.36 ± 0.06^{ab}	1.3 ± 0.1^{bc}	1.4 ± 0.12^{ab}	7.47	<0.001
K^+ ($cmol^+$/kg)	0.14 ± 0.02^{a}	0.18 ± 0.03^{a}	0.14 ± 0.02^{a}	0.18 ± 0.02^{a}	0.19 ± 0.03^{a}	0.2 ± 0.02^{a}	0.19 ± 0.02^{a}	1.04	0.405
HCO_3^- ($cmol^+$/kg)	0.21 ± 0.02^{ab}	0.21 ± 0.03^{b}	0.22 ± 0.01^{ab}	0.26 ± 0.08^{ac}	0.29 ± 0.01^{c}	0.28 ± 0.04^{c}	0.23 ± 0.02^{bc}	7.45	<0.001
$SO_4^=$ ($cmol^+$/kg)	0.44 ± 0.02^{a}	0.4 ± 0.02^{a}	0.42 ± 0.04^{a}	0.4 ± 0.09^{a}	0.44 ± 0.04^{a}	0.41 ± 0.02^{a}	0.4 ± 0.03^{a}	1.56	0.171

Due to physicochemical properties of soils in the Algerian hyper arid lands, such as the lack of cohesion between soil particles, low values of the organic matter, salinization…, ecosystems of this region are classified as degraded habitats (Halitim, 1998). Moreover, truffles were reported occurring in semiarid and arid areas of Algeria on calcareous soils that have sandy texture and very slight organic matter values (Fortas, 1990). Besides, it has been reported that *T. claveryi* and *T. nivea* occur in deserts of salty and/or gypseous soils (Singer, 1961; Halwagy and Halwagy, 1974; Alsheikh and Trappe, 1983; Bradai et al., 2013).

In general, soil properties of truffles biota in Northern Algerian Sahara are very similar to those reported in some truffle autoecological studies, whether in North Africa (Fortas, 1990; Khabar et al., 2001; Slama et al., 2006) or in the Middle East (Abd-Allah et al., 1989; Hashem and Al-Obaid, 1996; Al-Ruqaie, 2002; Mandeel and Al-Laith, 2007). However, our results are different from those observed in the Kalahari Desert, where the soil of truffle habitats had a low pH values ranging from 5.5 to 6.5; as well low total CaCO3 content (0.3 and 3.1%) (Taylor et al., 1995). This difference is probably due to multiple dissimilarities of regional landscape-type (geomorphology, hydrology and the type of habitat); climate patterns (temperature, precipitation and seasonality); soil traits (soil type and evolution); and the type of host plants (Díez et al., 2002).

Geomorphological parameters

In the Algerian Sahara, the producing areas of desert truffles occur especially in depressions (Daya) and beds of temporal Wadis. The trend towards these geomorphological zones is not random, it follows that these formations are characterized by their ability to accumulate rainwater, which promotes the development of truffles as well as its host plant species. Ozenda (2004) argues that the Wadis and Dayas (depressions) are among the most favourable biotopes for the installation of vegetation in the Saharan regions. In addition, Chehma et al. (2005) also demonstrated that the beds of Wadis are the richest and most diverse in species and plant families in the Northern Sahara habitats. Moreover, this area is well known for its richness of medicinal plants (Hadjaidji-Benseghier and Derridj, 2013).

Climatic parameters

According to our findings, the development and distribution of desert truffles in the Northern Algerian Sahara are mostly related to the existence of favourable habitats in relation to climate. Indeed, truffle development is closely related to climatic conditions, particularly rainfall, which mainly occurs during the fall and winter seasons (Figure 5). In fact, truffles thrive in warm climates provided in autumn and/or winter given quantities of rains fall then periods of drought follow. These rains, even of low-quantity, play important roles in the establishment of truffles including the transport and dispersion of fungal spores, spore germination and also the germination and development of host plant (*Helianthemum* spp.).

However, the production of truffles can be disrupted by excessive rainfall or rains poorly distributed during the year or even by prolonged periods of extreme heat or cold or even more prolonged periods of drought (Chafi, 2004). Indeed, we find that annual rainfall well distributed between October to March often give good results for harvesting desert truffles in Algeria, which takes place between January–February in the Saharan regions (arid climate) and from March to April in steppe regions, areas with semi-arid climate.

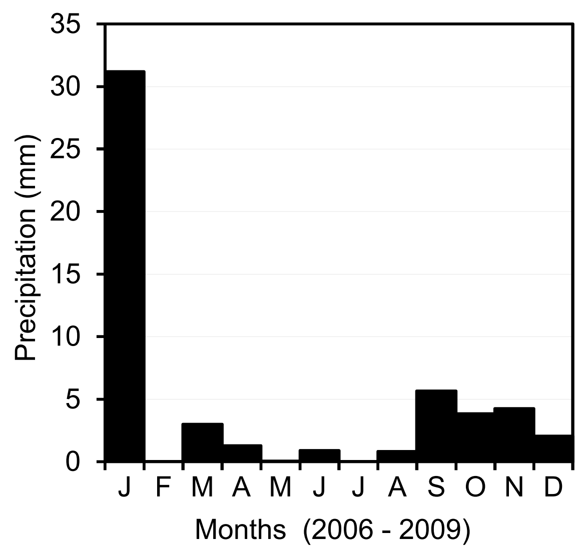

Figure 5. Variation in average monthly precipitation of Northern Sahara, Algeria during the period 2006–2009.

Based on our monitoring of desert truffles in the sites sampled throughout 2009 and for rainfall of 130.06 mm (NOM, 2010), truffle productivity was about 4.3 kg per hectare, knowing that for the same sites and during the year 2007, no production has been achieved since the rainfall did not exceed 51.05mm (NOM, 2008). The growth of fruiting bodies of truffles depends on several factors such as the periodicity of the rainy season including rainfall amount, types and characteristics of soil, water availability and climatic conditions (Bokhary and Parvez, 1988).

Generally, areas where desert truffles grow have an annual rainfall ranging from 50 to 380 mm. During the season of harvest, production yield of truffles is greater if the rainfall varies from 70 to 120 mm in the countries of North Africa and if it fluctuates between 100 to 350 mm in South European countries. The seasonal distribution of rainfall is as important as its quantity, i.e. the rain is required, for both fungi and host–plant growth, no later than early December in North Africa and the Middle East; and at least in early October in southern Europe (Morte et al., 2009).

Symbiotic host plant

Desert truffles surveyed in the Northern Sahara of Algeria establish symbioses with plant roots of the family Cistaceae, especially with *Helianthemum lippii*. The genus *Helianthemum* is well known in literature for the establishment of associations with truffles in several regions in the world (Dexheimer et al., 1985; Fortas and Chevalier, 1992; Díez et al., 2002; Mandeel and Al-Laith, 2007).

The species *Helianthemum lippii* is a small plant, very branched, of stiff stems and partially lignified, that measures up to 30 cm of height in good rainfall conditions. The leaves are opposite, oblong, covered with very short hair, which gives them a whitish green colour. Tiny yellow flowers of five petals, sessile as leaves, are visible in clusters (Ozenda, 2004).

Within the sampled sites, desert truffles are harvested in habitats characterized by a high density of the host plant. In addition to the syncing of truffle development with fall–winter rainfalls, there is a significant synchronization in the growth of the two symbionts, where the maturity of the desert truffles, assessed by the formation of asci, usually and timely corresponds to the flowering stage of the host plant.

Conclusion

The present taxonomic and bioecological study of desert truffles, conducted for the first time in Northern Algerian Sahara, has identified three species *T. arenaria*, *T. claveryi* and *T. nivea*. These species, living in association with *H. lippii* (Cistaceae), are few in number but have remarkable adaptations to the environment that is characterized by a severe aridity and rudimentary soil traits. Indeed, from an ecopedological point of view, the harvested truffles grow in moderately calcareous sandy soils, slightly alkaline and poor in organic and mineral matter. In terms of climate, these fungi grow in a hot arid climate, as long occasional rains occur in autumn–winter, then periods of drought follow. Future work is necessary to investigate truffles of the Algerian Sahara through studies at molecular scale (DNA sequencing, phylogeny, eco-physiology, and therapeutic and biotechnological benefits.

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