Journal of Materials and Environmental Science
ISSN : 2028-2508
e-ISSN : 2737-890X
CODEN : JMESCN

J. Mater. Environ. Sci., 2023, Volume 14, Issue 01, Page 13-30

http://www.jmaterenvironsci.com

Contribution to the study of the production factors of Moroccan truffles (Soil, Climate, Vegetation)

S. Hakkou[1]*, M. Sabir[2], N. Machouri[1]

[1]*Faculty of Letters and Human Sciences, Department of Geography BP. 1040 - Rabat, Morocco*
[2]*National Forestry School of Engineers, Department of Soil-Water-Biodiversity, BP 511, Salé, Morocco*
**Corresponding author, Email address: soukaina.hakkou@gmail.com*

Received *30 Dec 2022,*
Revised *02 Jan 2023,*
Accepted *04 Jan 2023*

Keywords:
- ✓ *Kingdom of Morocco*
- ✓ *Desert truffle,*
- ✓ *True truffles,*
- ✓ *Edaphic conditions,*
- ✓ *Climatic conditions.*
- ✓ *Host plants.*

Citation*: S. Hakkou, M. Sabir, N. Machouri, Contribution to the study of the production factors of Moroccan truffles (Soil, Climate, Vegetation), J. Mater. Environ. Sci., 14(1), 13-30.*

Abstract: The production of truffles depends on the interdependence of three main factors, the soil, the rainfall and the host plant. The areas where these factors accomplish their role are endowed with good productivity. The objective of this work is to contribute to the study of the production factors of Moroccan truffles. The study area concerns the four truffle regions of the Kingdom, namely: the Northeast region, the Maâmora forest, the Doukkala-Abda Sahel and the Moroccan Sahara. In addition to the Jaâba forest in the Middle Atlas known for the production of true truffles and the Zouada forest in Larache known for the production of *Terfezia arenaria*. The results of this study indicate that Moroccan truffles need two rainfall periods, the first concerns summer-autumn rain and the second concerns winter rain. The soils are generally sandy to loamy, poor in organic matter, faintly calcareous, with a pH around neutrality and not saturated with exchangeable bases. The host plants most present in the studied areas are Helianthemum species, except for certain species of Maamora and true truffles linked to the tree layer.

1. Introduction

The birth and development of truffles require the interdependence of three main factors: the soil, the climate and the host plant. The intensity and seasonal distribution of precipitation influence its yield and abundance. As for the soil, it plays a major role in their growth through its physicochemical characteristics. While the host plant, provides through a symbiotic association the nutrients (water, mineral elements) necessary for the development of this fungus (Grente and Chevalier, 1980; Dexheimer et *al*., 1985, Fortas and Chevalier, 1992; Laessoe and Hansen, 2007; Fortas, 2009; Bouziani et *al*., 2010; Bradai et *al*., 2013). The distribution and variability of species is mainly due to the difference between these factors from one region to another (De Laplane, 2010) .

There is a difference between these conditions between desert truffles and true truffles. As for desert truffles, also known as *terfez*, they are adapted to the climates of semi-arid and arid zones, hence their name "desert truffle". Their development is closely linked to autumn and winter rainfall. The regions where they develop are generally characterized by an annual rainfall of between 50 and 380 mm (Trappe, 1979; Malençon, 1973; Awameh, 1981; Feeney, 2002; Kagan-Zur and Roth-Bejerano, 2008, Abeysekara *et al.* 2023). According to Heim (1969), the good production of truffles depends on the abundance of rains in November and December. While for Alsheikh (1994), truffles appear after 3 to 4 months of good autumn and winter rainfall. This is the same period during which the host plant completes its life cycle. Rains, even small amounts, play an important role, particularly in the transport, dispersal and germination of ascospores. But excessive rains or bad distribution as well as prolonged cold periods or strong heats cause the disturbance of the biological cycle of the truffle and imply the rotting of the spores (Feeney, 2002 ; Bradai et *al.,* 2013, 2015 ; Khabar, 2016). Desert truffles prefer sandy soils, either gypseous, or gravelly-gypseous, well aerated and light allowing a better circulation of mineral elements, relatively rich in calcium carbonate and poor in organic matter and phosphorus. The majority thrive in soils with an alkaline or near-neutral pH. The pH and humidity are higher in the immediate environment of the *terfez* (subsurface) than on the surface. On the other hand, the organic matter content is low in the subsurface (Alsheikh and Trappe, 1983 ; Fortas, 1990 ; Fortas and Chevalier, 1992 ; Hashem and Al-Obaid, 1996 ; Bonifacio and Morte, 2014). As for the host plant, the terfess live in symbiotic association with plants belonging to the *Cistaceae* family, generally *Helianthemum* (Awameh and Alsheikh, 1980; Alsheikh and Trappe, 1983; Moreno et *al.*, 2000; Diez et *al*, 2002; Zambonelli et *al*, 2014) .

While for true truffles, of the genus *Tuber*, they develop in different climates depending on the species. They need alternating periods of heat and humidity. The factor limiting their development is frost. When it concerns the first five to twenty centimeters, it interrupts the growth and maturity of the ascocarps, degrades or kills the fruit of the fungus (Callot, 1999; Bernadach, 2008; Olivier et *al.,* 2018). In autumn, the constraint to be feared is an excess of rainfall which can lead to the rotting of the truffles when the ground is little or moderately filtering. Persistent droughts in October can also cause catastrophic damage (Olivier et *al*., 2018). These truffles thrive in calcareous soils with the presence of more or less fine elements including clay, airy and draining soils that heat up easily with intense biological activity. The role of clay is to structure the soil and regulate humidity. As for the biological activity, it provides the nutrients the truffle needs, as well as the aeration of the soil. It should be mentioned that permanent humidity is not good for the development of the truffle (Bernadach, 2008; Olivier et *al.,* 2018) . The *Tuber* live entirely in association with the roots of certain trees, mainly oaks Rodriguez, 2008). There are certain factors that favor a tree being truffle-hosting, including soil, climate and biotic factors. Among the trees considered as truffle-hosting according to tradition, we find: the holm oak (Quercus ilex), the pubescent oak (Quercus pubescens), the kermes oak (Quercus coccifera), the pedunculate oak (Quercus robur), the faginate oak (Quercus faginea), cork oak (Quercus suber), hazel (Corylus avellana) and lime trees (Tillia). Other trees can be truffle-hosting if the conditions are favorable such as hornbeam (Carpinus), Aleppo pine (Pinus halepensis), black pine (Pinus nigra) and chestnut (Castanea) (Olivier et *al.*, 2018).

In Morocco, there are four major truffle regions known mainly for the production of desert truffles, namely, the Northeast region which includes the Oriental region, High Moulouya and part of Tafilalet (*T. nivea*, *T. pinoyi*, *T. claveryi*, *T. boudieri*, *T. olbiensis*, *T. leptoderma* and *Picoa juneperi*) ; Maâmora forest (*T. arenaria*, T. *leptoderma*, *T. asa*, *T. oligospermum*, *T. gennadii*, *T. Borchii* Var. *sphaerosperma* and *Delastria rosea*), Doukkala-Abda Sahel (*T. boudieri*, *T. pinoyi* and *T. oligospermum*) and the Moroccan Sahara (*T. pinoyi*, *T. nivea*, *T. claveryi* and *Picoa juniperi*). Other areas also exist with rare and irregular production. The Middle Atlas is one of those areas whose holm oak forests are home to true truffles. The existing species are: *T. excavatum*, *T. brumale*, *T. rufum* and *T. uncinatum*/*aestivum*. The regions of Tangérois (Tangier), Loukkous (Larache), Souss (Agadir), Drâa (Ouarzazate) and the plantations of the green belt south of Rabat are home to desert truffles. Morocco is the first country in North Africa to introduce the cultivation of black truffles *Tuber melanosporum* in Debdou and Imouzzer du Kandar (Chatin, 1896; Malençon, 1973 ; Serrhini et *al.,* 1995 ; Khabar, 2016 ; Laqbaqbi, 2020 ; Hakkou et *al*., 2021 ; Hakkou et *al*., 2022).

The objective of this work is to contribute to the study of truffle production factors in the four major truffle regions of the Kingdom and in other areas including the Jaaba forest in the Middle Atlas and the Zouada forest in Larache which knows production of *Terfezia arenaria* the common species of Maâmora.

2. Methodology

2.1 Meteorological data

Rainfall data were collected from the forest services of the truffle regions. Then surveys with collectors were carried out to distinguish the years of good production. The knowledge of the average rainfall of the years of good production, will make it possible to specify the quantities of rain favorable to the production of Moroccan truffles.

2.2 Soil data

a. Collecting soil samples in the field

Soil samples were taken in the truffle regions, and in the forests of Jaaba in the Middle Atlas and Zouada in Larache in the places known by the collectors to be the most productive (**Figure 1, Table 1**). In the same location, 3 random soil samples were taken from the surface layer (0 – 10 cm) to measure soil apparent density (g/cm3) and another composite sample from the top 20 cm (0 – 20 cm) to perform conventional physicochemical analyzes in the laboratory (texture, pH, exchangeable bases, nitrogen, phosphorus, potassium, carbon, etc.).

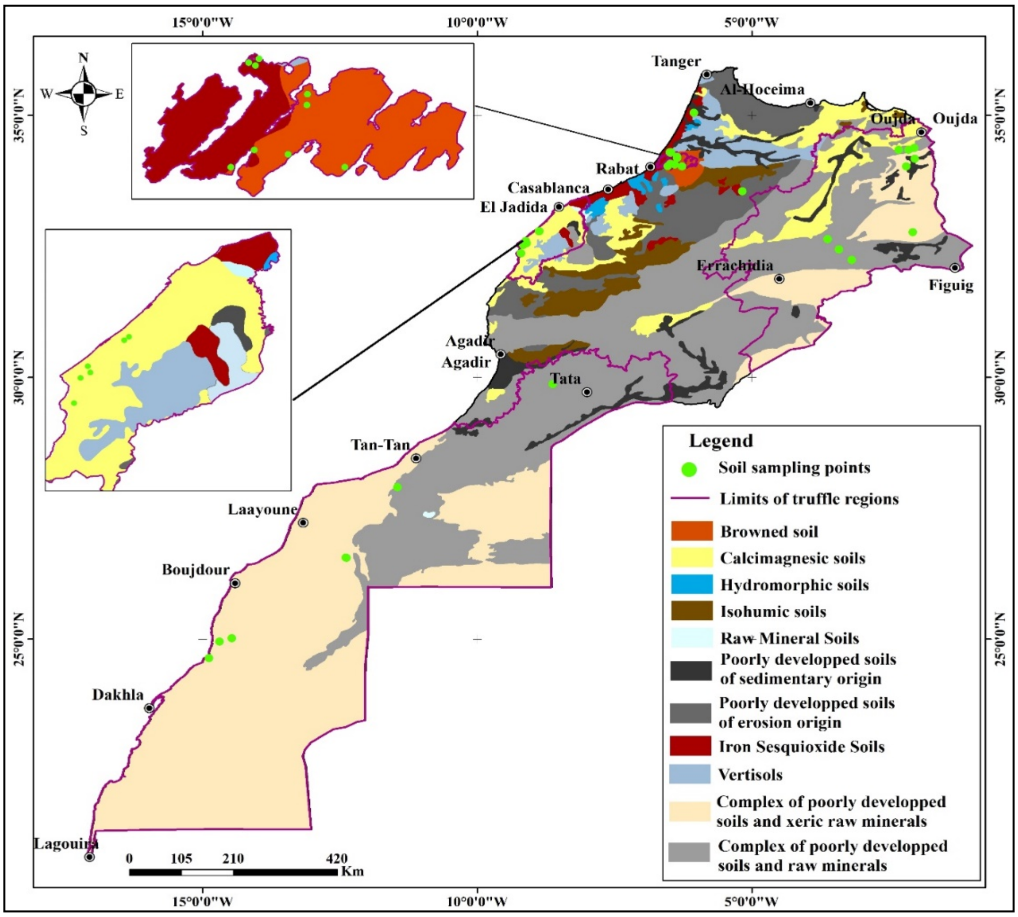

Figure 1. Soil sampling points

Table 1. Coordinates of soil sampling sites

Regions	Provinces	Communes	Sites	Coordinates
Northeast region	Jerada	Guenfouda	O1	34°22'47.92"N 2° 2'35.55"O
	Taourirt	Tancharfi	O2	34°20'30.33"N 2°19'21.23"O
	Jerada	Laaouinate	O3	34°20'34.53"N 2° 8'41.89"O
		Ain Béni Mathar	O4	34°10'24.29"N 2° 1'48.07"O
			O5	34° 1'40.98"N 2°11'10.72"O
	Figuig	Tandrara	O6	32°46'10.82"N 2° 4'8.58"O
		Beni Tadjite	O7	32°26'37.91"N 3°24'49.90"O
			O8	32°38'19.43"N 3°37'1.46"O
		Boumeryem	O9	32°14'36.84"N 3°10'46.46"O
Maamora	Khémisset	Sidi Allal El Bahraoui	M1	34° 2'8.27"N 6°32'6.54"O
			M2	34° 4'39.03"N 6°28'54.03"O
		M'qam Tolba	M3	34° 2'9.07"N 6°16'20.56"O
		Sidi Boukhalkhal	M4	34° 4'0.63"N 6°24'11.31"O
	Kénitra	Ameur Seflia	M5	34°12'45.00"N 6°21'30.73"O
			M6	34°11'10.03"N 6°21'36.73"O
		Ouled Slama	M7	34°17'18.57"N 6°29'39.75"O
			M8	34°16'53.73"N 6°28'43.85"O
			M9	34°17'53.27"N 6°28'14.85"O
Doukkala-Abda Sahel	El-Jadida	Ouled Ghanem	S1	32°46'8.31"N 8°53'40.02"O
			S2	32°47'26.95"N 8°51'59.27"O
	Safi	Ayir	S3	32°36'9.08"N 9° 6'59.61"O
			S4	32°33'46.82"N 9° 6'0.60"O
		El Beddouza	S5	32°31'39.70"N 9° 9'38.73"O
		Had Hrara	S6	32°22'4.53"N 9°11'57.79"O
Moroccan Sahara	Tata	Issafen	SA1	29°52'14.97"N 8°37'21.02"O
	Tan-Tan	Abteh	SA2	27°54'9.40"N 11°26'59.02"O

	Es-Smara	Sidi Ahmed Laarousi	SA3	26°26'20.71"N 12°38'47.49"O
			SA4	26° 6'15.05"N 12°29'2.58"O
	Boujdour	Jraifa	SA5	24°57'15.75"N 14°41'13.38"O
			SA6	25° 1'1.69"N 14°27'53.20"O
			SA7	24°38'25.41"N 14°52'48.79"O
Forêt de Jaâba	El Hajeb	Ait Naamane	J1	33°33'11.94"N 5°10'23.03"O
Forêt de Zouada	Larache	Zouada	Z1	35° 2'59.68"N 6° 3'13.36"O

b. Laboratory analyzes

The physicochemical analyzes carried out are:

- Particle size analysis ;
- Determination of total CaCO3 using Bernard's calcimeter;
- Determination of carbon and organic matter contents according to the method of Walkley and Black (1939);
- Determination of assimilable phosphorus according to the Olsen method;
- Determination of total nitrogen according to the Kjeldahl method (1883);
- Determination of exchangeable potassium using the flame spectrophotometer;
- Soil pH measurements with H2O and KCl using a pH meter;
- Determination of exchangeable bases (Ca2+ and Mg2+) using the technique developed by Lavkulich (1981), which consists of saturating soil samples with a buffered solution of ammonium acetate (1M) at pH 7.

2.3 Identification of host plants

Field trips were carried out between March 2020 and July 2022, during which we were able to participate in the collection of truffles, observe their natural production environment and collect and photograph their host plants which were subsequently identified through their vernacular names, botanical descriptions and collaboration with botanists from ENFI and the Forest Research Center.

3. Results and Discussion

3.1 Precipitation

Certainly, desert truffles are adapted to arid climates, but rainfall is the key factor for the germination of host plants and therefore for the production of truffles. The amounts of rain necessary for good production vary according to the specificities of each region and the species of truffle in question. According to surveys and participatory workshops, generally for a good production of truffles, the rains must fall in two periods. The first summer/autumn rains, thunderstorms from the end of August to the beginning of November, allow the germination of seeds and the installation of host plants in favorable places. The second winter rains, from December to March, allow the development of truffles as a fungus taking advantage of the symbiosis that settles between it and the roots of the host plant. The more the rains of this second period are important and fill the water reserve of the ground, the more the production is abundant and the wet grounds support the development of important calibers. Thus, the truffle harvest period is longer and can last until April-June, depending on the region.

Since the annual production of truffles at the national level is not measured and archived, it is difficult to specify favorable rainfall values for good productions. But, by referring to the averages recorded during the years declared as good productions by the collectors, we can give some indications on the favorable quantities (**Table 2**). The years considered to have good productivity by region are:

- **Northeast region:** 1993, 1994, 1995, 1997, 2002, 2007, 2008 and 2014. The last year of good production was 2018. The average rainfall recorded varies from 402.95 mm to 776.7 mm. Rainfall of the order of 195mm is capable of generating good production (Figuig in 1995);
- **Maâmora forest:** 1996, 2002, 2003, 2008, 2014, 2016 and 2018. The average recorded rainfall varies from 485 mm to 1236.4 mm;
- **Doukkala-Abda Sahel:** 2009, 2010, 2011, 2014 and 2016. The average rainfall recorded varies from 338.6 mm to 530.25 mm;
- **Moroccan Sahara:** from 2014 to 2017. The average rainfall recorded varies from 50.2 mm to 122.3 mm. Rainfall of the order of 37.6 mm is capable of generating good production (Dakhla in 2017)

All the years declared to be of good production recorded rainfall above the annual averages of the stations concerned. However, the collectors judge that it is the distribution of the rains in two periods, the first constituted by the summer and autumn storms and the second by the winter rains, which influences the production of the truffles the most. In addition, we note that these years are very irregular. They are unpredictable. There is no regular cyclical phenomenon that could be considered for their prediction. Indeed, for the northeast zone where we have more data, years of good production were more frequent during the 1990s than they were during the last decade. One would think that this is due to the effects of climate change. In the Moroccan Sahara and Sahel Doukkala, production has been rare, if not very low, in recent years. We note that in the Maâmora, they are more regular one year out of three. Overall, since 2019 productions have been described as low by collectors.

The difficulty of forecasting truffle production could be explained by the fact that rainfall in these semi-arid, arid and Saharan areas is characterized by a double inter-annual and intra-annual (between seasons) irregularity. Indeed, the calculation of the coefficients of variations shows that the precipitations are very variable in the Moroccan Sahara than in the other regions.

As for the Jaâba forest located in Ifrane in the Middle Atlas, it belongs to a zone with a subhumid to humid climate. It receives a fairly high amount of precipitation ranging from 700 to 1200 mm/year. The existing truffles in this forest are not subject to collection. The local population does not even know them, especially since they occur at a considerable depth and do not come out on the surface of the earth. Only truffle dogs can detect them.

Our results concerning the climatic conditions of desert truffles confirm the statements of Khabar (2016) saying that the production of desert truffles depends on favorable rainfall in early autumn for some species, and winter and spring for others. According to Khabar (2002), in the Maâmora forest, truffles require maximum rainfall before the month of March and a rainfall of 240 mm is quite sufficient to ensure good production. As for the eastern region, it was reported by El Aji (1999) that the two years, 1990/1991 and 1993/1994 were of good production in Bouaarfa. The rainfall recorded was of the order of 222.6 and 214 mm respectively.

Table 2. Rainfall in years of good truffle production in the truffle regions of Morocco

Years	Maâmora	Northeast region			Doukkala Abda Sahel		Moroccan Sahara	
	Rabat-Sale	Figuig	Jerada	Oujda	Sidi Msahel	El Jadida	Tan-Tan	Dakhla
1990	413	235	425	422,9				
1991	513,6	325	480	293,5				
1992	280,4	170	400	263,1				
1993	434,6	230	415	377				
1994	208,8	210	360	344,5				
1995	321,1	195	370	240,9			105,9	
1996	1091,7	275	445	393,7				
1997	545,3	215	315	352,3				
1998	261,4	120	340	324,1				
1999	418,8	190	385	248,1				
2000	504,2	130	265	225,8				
2001	349	85	375	243,3				
2002	683,4	215	395	252,9				
2003	602,5	220	530	305,6				
2004	619	205	480	310,4				
2005	404,9	225	320	217,1				
2006	505,2	275	400	235				
2007	514,9	225	485	346,7				
2008	848,9	510	645	358,4				
2009	651,5	285	435	249,9	385	475		
2010	951,8	210	540	322,1	283	394,2	283	
2011	424,4	370	495	300,6	438	449,7		
2012	414,2	300	505	305,4	143	474,3		
2013	402,9	160	480	202,2	82	348,6	71,4	
2014	576,3	405	405	306,3	535	525,5	153,5	52,8
2015	243,3	235	400	295,1	156	272,5	53,9	46,5
2016	485	225	455	240,5	444	496,4	197,1	47,5
2017	423,2	176	380	207	305	274,1	84,4	37,6
2018	1236,4	294	498	325	274	577,7	19,8	15,7
2019	397,4	236	440	266,4	232,5	251,4	40,1	5,3
2020	348,7	211	415	241,5	347	320,7	42,7	16,8
2021	505,3	123	327	153,7	74,5	315,8	48,7	0,8
P (mm/y)	518,2	233,9	425,2	286,6	283,9	397,7	100,0	24,8
SD (mm/y)	234,0	85,1	77,4	61,2	144,5	108,2	80,6	21,4
CV (%)	45,2	36,4	18,2	21,4	50,9	27,2	80,5	86,2

(P: mean annual precipitation, SD: standard deviation, CV coefficient of variation).

Just like Moroccan truffles, truffles from Algeria occur in arid, semi-arid and Saharan areas. They develop in a warm climate characterized by good autumn and/or winter precipitation, followed by a period of drought. For good production, three rainy periods are necessary. These are the stormy rains of late summer and early autumn, rains of October, November and March. Favorable rainfall is around

40 to 60 mm during October and November and 5 to 15 mm in March, followed by a period of drought in April (Bouchareb, 1994; Tadja, 1996; Fortas, 2004, Boufeldja, 2017; Benattia and Messaoudi, 2018). Rainfall from September to April allows the germination of truffle ascospores and the growth of the mycelial, while that of spring allows their maturation (Derbali, 2021). In Kuwait, truffle development requires a minimum rainfall of 180 mm distributed from October to March (Awameh and Alsheikh, 1979).

As for true truffles, *T. brumale*, called the musk truffle, is adapted to the Mediterranean climate but also appreciates oceanic and suboceanic climates. As for *T. uncinatum* grows in very different climates: oceanic, semi-continental, continental and mountainous Mediterranean. It is favored by the abundant rains in summer, in June, July and August (60 to 130 mm/month). It reaches maturity before extreme cold and therefore avoids the risk of frost (Callot, 1999; Bernadach, 2008) . The *T. aestivum* species from Iran is found in a humid temperate climate, with an annual rainfall of around 350 to 676 mm, and a daily rainfall of 65.2 to 90 mm maximum (Puliga et *al.*, 2021). In Morocco, the Tuber are found in subhumid and humid climates (Khabar, 2016).

3.2 The truffle soils of Morocco

The soils in most of the areas studied have a high sand content ranging from 13.5 to 87.5%, an average silt content ranging from 7.5 to 66.5% and a low clay content ranging from 5 to 20%. Thus, the soils are all sandy and loamy in texture, light favorable to the production of truffles. The clay contents are low. They are loose to slightly dense soils (**Table 3**).

The apparent density values range from 0.75g/cm3 as the minimum value in the holm oak forest of Ifrane to 1.76g/cm3 as the maximum value in the cork oak forest of Larache. The average apparent density for the surface horizon (0-10 cm) is 1.35 g/cm3. According to Linsley et *al.* (1982) and Poffijn (1988), the typical value for sandy soils is 1.52 g/cm3, for loamy soils is 1.36g/cm3 and for loamy-sandy soils 1.44g/cm3.

Table 3. Textures and apparent density of the soils of the truffle areas of Morocco

Zones	Clay %	Silt %	Sand %	Texture	Apparent density (g/cm^3)
Northeast region	13,6	37,19	49,19	Loamy	1,38
Maamora forest	5	7,5	87,5	Sandy	1,47
Doukkala-Abda Sahel	7	17,4	75,6	Sandy-loamy	1,58
Moroccan Sahara	11,37	30,93	57,7	Loamy-sandy	1,67
Jaaba Forest, Middle Atlas	20,0	66,5	13,5	Fine loam	0,75
Zouada Forest, Larache	10,0	7,8	82,2	Sandy-loamy	1,76

The chemical analyzes carried out for these soils (**Table 4**) indicate that they have slightly acidic, neutral to slightly alkaline pH values. They have very variable total CaCO3 contents between zones, ranging from non-calcareous soil to low-calcareous soil. Some sites present quite high contents, we note the O7 site in the Northeast region with a value of 14.84%. The SA1 site in the Moroccan Sahara with a value of 10.4%. And the two sites S3 and S5 in the Sahel of Doukkala-Abda which present respectively 13.63% and 11.18%.

They are generally poor in organic matter in the superficial horizons, except in the Middle Atlas which has a very rich content of 12.36%.

The levels of assimilable phosphorus (P2O5) are very variable ranging from a very low level (Maamora, Moroccan Sahara and Zouada), low (Northeast), well provided (Jaaba) to a high level (Doukkala-Abda Sahel) according to the standards of Delaunois (2008).

The exchangeable potassium contents are very variable between the zones. Ranging from a very low content (Maamora and Zouada), low (Doukkala-Abda Sahel) to a very high content in the Northeast region, the Moroccan Sahara and Jaaba. The latter has the highest value 1018.23mg/kg (according to the standards of Delaunois (2008).

C/N ratios are low in all arid areas and indicate rapid mineralization of organic matter. It is quite high in the humid Middle Atlas where it indicates an accumulation of organic matter on the surface. For the exchangeable bases (Na+, Ca2+ and Mg2+), we note that the values are very variable between the zones, but indicate that these soils are not saturated with bases. The soils are relatively rich in Ca2+ except for the forests of Maamora and Zouada occupied by cork oak. Indeed, this essence is qualified as being calcifuge.

Table 4. Chemical characteristics of the soils of the truffle areas of Morocco

Parameters		Zones					
		Northeast région	Maamora forest	Doukkala-Abda Sahel	Moroccan Sahara	Jaaba forest	Zouada forest
pH	H_2O	8,38	6,20	7,6	8,37	7,56	5,85
	KCl	7,7	5,72	7,18	7,90	6,96	5,57
% $CaCO_3$		5,76	0	4,13	4,58	0	0
% H_2O		1,14	0,23	1,08	1,66	1	0,3
% Organic matter		1,68	1,95	2,65	0,55	12,36	0,72
%Carbon		0,97	1,13	1,53	0,32	7,17	0,42
%Nitrogen		0,22	0,13	0,12	0,13	0,17	0,03
C/N		3,88	9,97	13,7	2,52	40,96	14,84
P_2O_5 (mg/Kg)		15,45	6,54	60,3	14	43,47	3,51
K_2O (mg/Kg)		397,65	57,57	62,77	306,4	1018,23	57,24
K+ (meq/100g)		0,83	0,12	0,13	0,64	2,14	0,12
Na+ (meq/100g)		0,37	0,26	0,32	1,03	0,39	0,20
Ca^{2+} (meq/100g)		23,91	2,53	13,66	22,06	18	1,75
Mg^{2+} (meq/100g		2,69	1,19	2,33	4,68	5	1,25

Moroccan desert truffles need well-structured, airy sandy soils, allowing the circulation of mineral elements. The soil texture of the Maamora sites is similar to those found by several authors, including Khabar (2002), Oubrahim (2015) and Aroui-Boukbida et *al.* (2016). Khabar (2002), working on truffles, noted that the sand content was in the range of 78.9% to 87% with an average of 83.77%. According to Abourouh (2020), Maamora's truffle are found in light, well-aerated soils with a sand content ranging from 80% to 90% weakly mixed with silt and clays. The water pH of the samples studied is close to that found by Khabar (2002), Oubrahim (2015) whose values were 6 to 5.5. According to Abourouh (2020), the pH of truffle sites in the maâmora is slightly acidic, close to 6. With regard to organic matter, the value found exceeds those found by Khabar (2002) considered extremely low (0.19 and 0 .57%). The phosphorus content (6.54mg/kg) is lower than those recorded by Khabar (2002) of 7.63 and 8.38mg/kg.

The value of K^+ (0.12 meq/100g) is lower than those recorded by Khabar (2002) of 0.21 and 0.50 meq/100g. The Ca^{2+} value (2.53meq/100g) is slightly lower than those recorded by Khabar (2002) of 2.61 and 2.99meq/100g. The value of Mg^{2+} (1.19meq/100g) greatly exceeds those reported by Khabar (2002) of 0.21meq/100g and 0.33meq/100g. And the value of Na^+ (0.26meq/100g) greatly exceeds those recorded by Khabar (2002) of 0.06meq/100g.

In comparison with Algerian truffles, *Terfezia arenaria* -the common truffle between Maâmora and Zouada- fruits in the same texture as that found by Aïbeche (2008) in the Algerian coast and who reports that this species occurs in sandy soils with a content of 89.06% and 92.42%. The nitrogen (N) value recorded in Zouada (0.03%) is very low in comparison with that of Maâmora (0.13%) and slightly exceeds the value recorded in the Algerian coast by Aïbeche (2008) from the order of 0.022%. For the C/N ratio, the value of Zouada (14.84%) exceeds that of Maâmora (9.97%) and approaches the values of the truffle soil studied by Aïbeche (2008) of 16.36 and 19.36%.

For the Oriental region, the pH of our samples (8.38) is close to the value found in the province of Figuig (8.25) by Bermaki et *al*., (2017) and in the region of Oriental (8.23) by Bouziani (2016). The CaCO3 value reported by Bouziani (2016) of 10.2% greatly exceeds ours. The organic matter content of 1.68% confirms the words of El Aji (1999) who indicate that in the north of the high plateau area, the soils contain 1 to 3% organic matter on the surface. The nitrogen content of the samples studied greatly exceeds that found by Bouziani (2016) by 0.05%. The phosphorus content of the sites studied of 15.45mg/kg is much higher than that found by Bouziani (2016) of 10.4mg/kg. And those found by Bermaki et *al*., (2017) in the order of 12.83mg/kg and by Tahiri (1997) in the order of 12.21mg/kg. The potassium content of around 397.65mg/kg is close to that found by Bermaki et *al*., (2017) in Figuig of around 389.86mg/kg. Note that the potassium levels found by other authors are 490mg/kg for Bouziani (2016) and 577.3mg/kg for Tahiri (1997).

For the Doukkala-Abda Sahel, it has a sandy-loamy texture. A successful cultivation experience of *Terfezia boudieri* - which is the most common species in the Sahel - conducted by Slama et al. (2010) in Tunisia was made on sandy-loamy soil. The pH in the same experiment is 7.1 value close to that recorded by the present study of 7.6. With regard to organic matter, the value recorded by our study (2.65%) exceeds that of one of the two sites of the experiment having a value of 1.17% and it is lower than the value of the other (4.94%) Slama et *al.* (2010). The phosphorus content of 60.2mg/kg is very low compared to those reported by Slama et *al.* (2010) of 212 and 575mg/kg. While the potassium value greatly exceeds those recorded by Slama et *al.* (2010) of 12.8 and 27.27mg/kg.

For the Moroccan Sahara, the sandy and loamy texture of the soil studied is the favorable texture for the production of truffles. Desert truffles generally grow in light sandy, arenaceous soils consisting of fine silt according to Heim (1967). A study conducted by Bradai et *al*., (2013) in the Algerian desert on *Tirmania nivea*, which is among the existing species in the Moroccan Sahara, reported that the production soils are sandy with a very loose particle structure. The pH value of 8.37 approaches that found by Bradai et *al*., (2013) of the order of 8.25 and exceeds that found by Bradai et *al.* (2014) of the order of 7.85. With regard to organic matter, the content is also poor for the two studies. Ours is 0.55%, it slightly exceeds that recorded by Bradai et *al*., (2013) of the order of 0.41% and it is lower than that recorded by Bradai et *al*., (2014) of the order of 0.87%. In Iran, the value greatly exceeds those recorded in our sites and those in Algeria. Thus, the average recorded by Jamali and Banihashemi (2012) is 2.01%. The phosphorus content of 14 mg/kg is very low compared to that reported by Bradai et *al*., (2014) of 23.04 mg/kg. As for the exchangeable bases, our values exceed those recorded by Bradai et al., (2014). Thus, for Ca^{2+} the values are 22.06 meq/100g and 5.24 meq/100g respectively. For Mg^{2+}

the values are 4.68meq/100g and 1.34meq/100g. And for K^+ the values are 0.64meq/100g and 0.17meq/100g respectively.

In general, Algerian truffles grow in slightly alkaline soils with a pH that varies between 7.85 and 8.57; sandy or calcareous sandy-loam, well aerated and light allowing better circulation of mineral elements, relatively poor in organic matter, rich in magnesium, well supplied with potassium and calcium, and poor in phosphorus (Fortas, 1990; Fortas and Chevalier, 1992b; Bradai, 2006; Zitouni et *al*., 2007; Aibeche, 2008, Benattia and Messaoudi, 2018). These conditions may vary between coastal regions and steppe regions (Derbali, 2021). In Kuwait, they are fond of either gypsum or salty gravelly-gypsum soils (Halwagy and Halwagy, 1974a and b).

With regard to true truffles, our results roughly agree with the words of Khabar (2010) saying that the species of Tuber harvested in Morocco are found in strongly calcareous soils of silty-clayey textures, rich in potassium, nitrogen and magnesium. According to Callot (1999), *T. uncinatum*/*T. aestivum* -one of the existing species in Jaâba- prefers organic clay soils, weakly acidic often without litter. In Iran, the production areas of this species are characterized by high pH sandy soils with a high CaCO3 content and a low amount of organic matter (Jamali and Banihashemi, 2012). According to Robin et *al*. (2016), the soil pH range in water where *T. uncinatum*/T. aestivum fructifies ranges from 5.9 to 8.4. Our results are different except for the pH values. Our soils are loamy and have a very high level of organic matter. The loamy texture is found in the variety of textures indicated by Robin et *al*. (2016), as favorable for the production of *Tuber aestivum* and which are: clay, clay-loam, loamy, sandy-loamy, loamy-sandy and sandy clay loam. True truffles can be harvested from soils that contain low to high percentages of sand (2.8 to 79.8%), low to high percentages of silt (9.8 to 67.4%), and percentages of low to medium clay (5 to 55%). A study conducted in Hungary by Gógán et *al*, (2012) on soils producing Tuber aestivum showed that 40% of the soils are loamy and 50% are loam-clay.

As for the exchangeable bases, the value of K^+ (2.14meq/100g) exceeds the values found by García-Montero et *al*, (2008) in Spain ranging from 0.07 to 1.97meq/100g, and those found by Hilszczańska et al. *al*, (2019) in Poland ranging from 0.34 to 1.27meq/100g. The Ca^{2+} value (18meq/100g) approaches some values reported by García-Montero et *al*, (2008) ranging from 4.77 to 30.71meq/100g. One site records a value of 18.63meq/100g. The value of Mg^{2+} (5meq/100g) greatly exceeds the values of the sites recorded by García-Montero et *al*, (2008) except for certain sites whose values are 6.31; 7.03 and 8.35meq/100g. The value is close to the average of the values recorded by García-Montero et *al*, (2008) of the order of 4.87 meq/100g. The value of the studied site greatly exceeds all the values reported by Hilszczańska et *al*. (2019) ranging from 0.57 to 2.14meq/100g. The Na+ value (0.39meq/100g) greatly exceeds the majority of the values recorded by García-Montero et *al*, (2008) except for certain sites which record high values of the order of 2.20 and 4.61meq /100g. And it greatly exceeds the values recorded by Hilszczańska et al. *al*, (2019) ranging from 0.03 and 0.087meq/100g.

3.3 Host plants

To find the truffle, one must first find its host plant. Collectors who have been able to discover this relationship of symbiosis by observation and by linking the places of production with the places of distribution of the plants host, are being seen walking with their heads down in search of the plants they already know. The host plants are generally *Helianthemum* called *Tegcis* or *laqsid* (القصيد= place of destination), because they indicate the existence of the truffle in a specific place. Other vernacular names are attributed to these plants specific to each region (**Figure 2**). At the level of the Maamora forest, certain species of truffles are associated with trees.

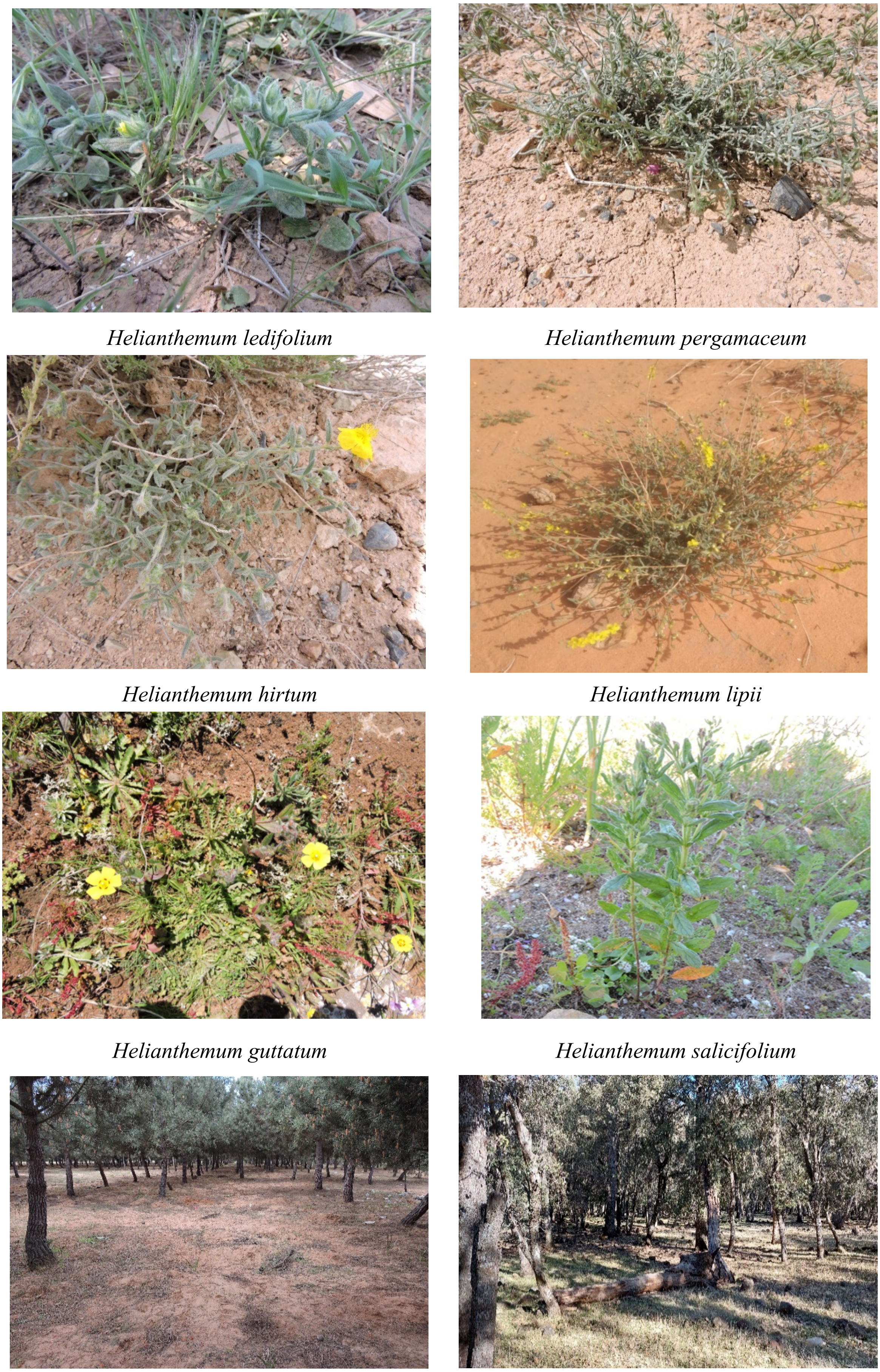

Figure 2. Host plants of Moroccan truffles

The plants encountered by region are:

- **The North-East region:** *Helianthemum ledifolium* locally called *Tegcis* or *Tzaoua*, *Helianthemum pergamaceum* locally called *Serd Amalou* or *Izefzaf*, *Helianthemum hirtum* locally called *Idoudi* and *Helianthemum lipii* locally called *Reguig*;
- **The Maamora forest:** *Helianthemum guttatum* locally called *Tegcis* and *Pinus pinaster* var. *atlantica* locally called *Taida*;
- **The Doukkala-Abda Sahel:** *Helianthemum guttatum* and *Helianthemum salicifolium*, both are locally called *Tegcis* or *laqsid*;
- **The Moroccan Sahara:** the most common host plant is *Helianthemum lipii* locally called *yarguig* or *Izzi*.

Regarding the Jaaba forest in the Middle Atlas, truffles live in symbiosis with the holm oak (Quercus ilex). As for the Zouada forest in Larache, they live with Helianthemum guttatum.

The species of host plants found in the studied areas (**Figure 2)** are among the species indicated by several authors. Thus, according to Tahiri (1997) and (Khabar 1988 and 2016), Moroccan truffles are harvested near herbaceous plants of the *Helianthemum* genus, in particular *H. apenninum*, *H. apertum*, *H. croceum*, *H. glaucum*, *H. guttatum, H. hirtum*, *H. ledifolium* and *H. Lipii*, *Cistus* including *Cistus halimifolius*, *C. ladaniferus*, *C. salicifolius*, *C. monspeliensis* and *C. salvifolius* and also pines, *Pinus halepensis* and *P. pinaster* var. *Atlantica*.

Other Arab countries also share the same plant species. In Algeria, truffles live in symbiosis with *H. guttatum*, *H. hirtum* var. *deserti, H. ledifolium*, *H. lipii*, *H. salicifolium*, *H. squamatum* and *Plantago albicans* (Fortas, 1990, Zitouni-Haouar et *al*, 2014, Zitouni-Haouar, 2016). In Kuwait, they live in symbiosis with *H. ledifolium* and H. *salicifolium* (Awameh and Alsheikh, 1979). Other plants have been reported in other countries *H. almeriense*, *H. ovatum*, *Artemisia herba alba* and *Plantago albicans* in France (Janex-Favre et *al*, 1988, Gutierrez et al, 2003; Kovacs et *al*, 2003). Existing *Tuber* species in Morocco are harvested under holm oak (Khabar, 2016).

Conclusion

In this study, it emerged that the production of truffles in the studied areas requires specific common conditions for certain factors and different for others. Generally, they need two rainfall periods, the first in summer/autumn and the second in winter. As for the soils, we can consider that the soils of the truffle areas of Morocco are sandy to loamy, poor in organic matter, calcareous ($CaCO_3$) contents generally low, with a pH around neutrality and not saturated with exchangeable bases. This study provided data on truffle soils that have never been studied, including the soils of the Moroccan Sahara, the Doukkala-Abda Sahel and the Zouada forest. The host plants most present in the studied areas are *Helianthemum* species, except for certain species of Maamora and true truffles linked to the tree layer.

Knowledge of the conditions of truffle production will contribute to their protection. And this by trying not to destroy their natural environment and to move towards cultivation trials based on this knowledge.

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest. *Compliance with Ethical Standards:* This article does not contain any studies involving human or animal subjects.

References

Abeysekara W. C. S. M., Siriwardana M., Meng S. (2023). Economic consequences of climate change impacts on the agricultural sector of South Asia: A case study of Sri Lanka, *Economic Analysis and Policy,* 77 : 435-450, ISSN 0313-5926, https://doi.org/10.1016/j.eap.2022.12.003

Abourouh M., (2020). Terfess et truffes de la Maâmora : importances biologique, écologiques et socio-économique. Consultation nationale "Restauration de la forêt de chêne-liège pour le développement et la valorisation des truffes dans la forêt de la Maâmora, FAO : 78 pages.

Aïbèche C., (2008). Caractérisation écologiques et mycologiques d'une espèce de terfez du littoral Ouest algérien. Essai de mycorhization contrôlée avec sa plante-hôte naturelle Helianthemum guttatum. Mémoire de Magister.Univ d'Oran. Es-Sénia. 85p.

Alsheikh A.M., Trappe J.M. (1983a). Desert truffles: The genus Tirmania. Trans. Br. *Mycol. Soc*., 8 (1): 83-90.

Alsheikh A.M., (1994). Taxonomy and mycorrhizal ecology of the desert truffles in the Genus Terfezia. Ph.D. dissertation. Oregon State University, Corvallis, 239 p.

Aroui-Boukbida H., Nabil H., El Ghaddari M., Smaili L., Grimaldi M., (2016). Caractérisation du sol de la subéraie et des plantations d'eucalyptus de la Maâmora au Maroc. Rapport technique. Département Transferts dans la Zone critique (TZC), UR. Fonctionnement biophysique du sol, Institut d'écologie et des sciences de l'environnement de Paris, IRD, 39 pages.

Awameh M. S., (1981). Response of Helianthemum salicifolium and H. ledifolium to infection by the desert truffle Terfezia boudieri. Mushroom science. XI. Part II. In *Proceedings of the Eleventh International Scientific Congress on the Cultivation of Edible Fungi*, Australia, edited by NG Nair, AD Clift, pp 843–583.

Awameh M.S., Alsheikh A. (1979). Laboratory and field study of four kinds of truffle (Kamah), Terfezia and Tirmania species, for cultivation. *Mush.Sc*. 10 :507-517.

Awameh M.S., Alsheikh A., (1980). Ascospore germination of black kamé (Terfezia boudieri). *Mycologia*, 72 : 50–54.

Benattia Z., Messaoudi S., (2018). Etude de Les activités antimicrobiennes et dosage des composés phénoliques des extraits de terfez (Terfezia arenaria. Chatin). Mémoire de master. Université Mohamed Boudiaf - M'sila. 97 pages.

Bermaki F-Z., Khabar L., Ezzanega A., (2017). Bioecology of desert truffles in the province of Figuig in Eastern Morocco. *Scientia Fungorum*. 46 : 29-36.

Bernadach P. (2008). Forêts de France- N° 518. 16 Pages.

Bonifacio E., Morte A., (2014). Soil Properties. In Kagan-Zur V., Roth-Bejerano N., Sitrit Y., Morte A., (eds), *Desert Truffles Phylogeny, Physiology, Distribution and Domestication, Soil Biology*, 38: 57-67, Springer, Berlin.

Bouchareb F., (1994). Etude écologique des terfez, cas de la région d'Ain Sefra (Wilaya de Naâma). Mém. Ing. D'état. Agron., I.N.F.S.A. Mostaganem. 81 pages.

Boufeldja W., (2017). Evaluation du potentiel nutritionnel et antioxydant de quelques variétés de Truffes du Sud-ouest algérien. Effets antimicrobien et antiinflammatoire. Thèse de doctorat. Université Djillali Liabes. 112p.

Bouziani N., (2009). Contribution à l'étude et à la mise en valeur du potentiel truffier de la région orientale du Maroc. Thèse. Université Mohammed Premier, Faculté des Sciences Oujda. 177 pages.

Bouziani N., Boukka M., Belabed A., Tahri E.H., (2010). Le Terfess au Maroc Oriental : Isolement et culture in vitro- *Rev. Microbiol. Ind. San et Environn*. 4, N°2, p : 110-120.

Bradai L., (2006). Contribution à l'étude bioécologique de la truffe blanche de désert (Terfezia sp) cas de la région d'Oued Mya (Ouargla). Thèse de Magister. Univ. Kasdi Merbah, Ouargla

Bradai, L., (2014). Inventaire et bioecologie des terfez dans quelques régions du Sahara septentrional (oued M'ya, oued Righ et Ghardaïa). Thèse de doctorat ès science. Université Kasdi Merbah – Ouargla. 124 pages.

Bradai L., Bissati S., Chenchouni H., (2013). Étude mycologique et bioécologique de la truffe blanche du désert (Tirmania nivea Desf. Trappe (1971) dans la région de Oued M'ya (Ouargla, Sahara Algérien). *Revue des BioRessources*, 3(1) : 6-14. https://doi.org/10.12816/0008856

Bradai L., Neffar S., Amrani Kh., Bissati S., Chenchouni, H., (2015). Ethnomycological survey of traditional usage and indigenous knowledge on desert truffles among the native Sahara Desert people of Algeria. *Journal of Ethnopharmacology*. 162, 31-38, https://doi.org/10.1016/j.jep.2014.12.031

Callot G., (1999). La truffe, la terre, la vie. Ed. INRA., Paris, 209 p.

Chatin A., (1896). Un terfas d'Espagne et trois nouveaux terfas du Maroc-. *Bull. Soc. Bot.* France, 43 :397-399. https://doi.org/10.1080/00378941.1896.10830694

De Laplane D., (2010). Des truffes sauvages aux truffes cultivées en loudunais. Mémoires de l'Académie des Sciences, Arts et Belles-Lettres de Touraine, tome 23, p. 215-241.

Delaunois A., Ferrie Y., Bouche M., Colin C., Rionde C., (2008). Guide pour la description et l'évaluation de la fertilité des sols. Chambre d'agriculture du Tarn et INRA de Montpellier. 96 pages.

Derbali S., (2021). Les paramètres bioécologiques des truffes du désert. Mémoire de master. Faculté des sciences exactes et des sciences de la nature et de la vie. Université de Biskra. 53 pages.

Dexheimer J., Gerard J., Leduc J.P., Chevalier, G., (1985). Comparative ultrastructural study of symbiotic mycorrhizal associations between Helianthemum salicifolium-Terfezia claveryi et Helianthemum salicifolium-Terfezia leptoderma. *Canadian Journal of Botany*, 63: 582–591. https://doi.org/10.1139/b85-073

Diez J., Manjon J.L., Martin F., (2002). Molecular phylogeny of the mycorrhizal desert truffles (Terfezia and Tirmania), host specificity and edaphic tolerance. *Mycologia*, 94(2), 247–259. https://doi.org/10.2307/3761801

El Aji A., (1999). Contribution à l'étude des Terfez des parcours de l'oriental marocain : germination des ascospores in vitro et mycorhization de l'Helianthemum ledifolium. Mémoire de troisième cycle en agronomie, Ecole nationale d'agriculture, Meknès. 84 pages.

Feeney J., (2002). Desert truffles galore. *Saudi Aramco World*. Pp 22–27.

Fortas Z., Chevalier G., (1992a). Caractéristiques de la germination des ascospores de Terfezia arenaria (Moris) Trappe, récoltée en Algérie. *Cryptogamie Mycol*., 13 : 21-29.

Fortas Z., Chevalier G., (1992b). Effet des conditions de culture sur la mycorhization de l'Helianthemum guttatum par trois espèces de terfez des genres Terfezia et Tirmania d'Algérie. *Canadian Journal of Botany*. 70, Number 12 : 2453-2460. https://doi.org/10.1139/b92-303

Fortas Z., (1990). Etude de trois Terfez. Caractères culturaux et cytologie du mycélium isolé et associé à l'Helianthemum guttatum. Thèse Doctorat d'état, université d'Oran Es-Sénia pp 9-68.

Fortas Z., (2004). Ecologie et production naturelle des terfez d'Algérie. Premier symposium sur les champignons hypogés du bassin méditerranéen, Rabat (Maroc), p 24-25.

Fortas Z., (2009). Diversité des espèces de terfez (truffes des sables) des zones arides algériennes. Séminaire international : Protection et préservation des écosystèmes sahariens « Ouargla », p 51.

Garcia-Montero LG., Diaz P., Martín-Fernandez S., Casermeiro M-A., (2008). Soil factors that favour the production of Tuber melanosporum carpophores over other truffle species: a multivariate statistical approach. *Acta Agric Scand* B-S P 58(4):322–329. https://doi.org/10.1080/09064710701743286

Grente J., Chevalier G., (1980). La trufficulture, un or noir, pour la Région Méditerranéenne. *Forêt Méditerranéennes* t. l n° 2 : 151 - 1 62.

Gutiérrez A., Morte A., Honrubia, M., (2003) Morphological characterization of the mycorrhiza formed by Helianthemum almeriense Pau with Terfezia claveryi Chatin and Picoa lefebvrei (Pat.) Maire. *Mycorrhiza* 13 :299-307. https://doi.org/10.1007/s00572-003-0236-7

Hakkou S., Sabir M., Machouri N., (2022) b. Le Maroc truffier : la répartition géographique des truffes et truffes du désert et leur productivité. *Rev. Mar. Sci. Agron. Vét*. 10(3). Pp : 395-407.

Hakkou S., Sabir M., Machouri N., (2021). Truffles from the northeast region of the kingdom of Morocco: geographical distribution and production potential. *International Journal of Current Research*, 13, (09).

Halwagy R., Halwagy M., (1974a). Ecological Studies on the desert of Kuwait: I. *The physical environment of the university of Kuwait* (Science). (1):75-86p.

Halwagy R., Halwagy M., (1974b). Ecological Studies on the desert of Kuwait: II. *The Vegetation. Journal of the University of Kuwait* (Science), 1, 87-95.

Hashem A.R., Al-Obaid, A. M. (1996). Mineral composition of soil and wild desert truffles in Saudi Arabia. *Journal of King Saud University*, Science 8(1): 5-10.

Heim R., (1969). Champignons d'Europe. Ed. Boubée et Cie: 223-235.

Hilszczańska D., Szmidla H., Sikora K., Rosa Gruszecka A., (2019). Soil Properties Conducive to the Formation of Tuber aestivum Vitt. Fruiting Bodies. *Polish Journal of Environmental Studies*, 28, 1713–1718.

Jamali S., Banihashemi Z., (2012). Hosts and distribution of desert truffles in Iran, based on morphological and molecular criteria. *J. Agr. Sci. Tech*. 14: 1379-1396.

Janex-Favre M.C., Parguey-Leduc A., Riousset L., (1988). The hypogeous ascocarp of the French species Terfezia leptoderma Tul., Tuberales, Discomycetes]. *Bull. Soc. Mycol*. Fr., 104: 145-178.

Kagan-Zur V., Roth-Bejerano N., (2008). Desert Truffles. *Fungi* 1(3):32–37p.

Khabar L., (1988). Le genre Terfezia Tull. Terfass) de la Forêt de la Maâmora (Région de Salé) : étude systématique, écologique, morphologique, cytologique et ultra structurale. Université Mohammed V, Rabat. Thèse de troisième cycle.

Khabar L., (2002). Etudes pluridisciplinaires des truffes du Maroc et perspectives pour l'amélioration de production des "Terfess" de la forêt de la Maâmora. Doctorat d'Etat Es- Sciences, Université Mohamed V, Faculté des Sciences, Rabat, Maroc. 167p.

Khabar L., (2010). Contribution to the study of the ecology of Tuber aestivum in Morocco. *Österr*. Z. Pilzk. 19. Pp : 261-264.

Khabar L., (2016). Les Terfess et les truffes du Maroc, biodiversité et valorisation. Éd. Univ. Européenne. 276 pages.

Kovacs G.M., Vagvolgyi C., Oberwinkler F., (2003). In Vitro interaction of the truffle Terfezia terfezoïdes with Robinia pseudoacacia and Helianthemum ovatum. *Folia Microbiol*., 48 (3): 369-378. https://doi.org/10.1007/BF02931369

Laessoe T., Hansen K., (2007). Truffle trouble: what happened to the Tuberales, *Mycological Research*, 111:1075–99. https://doi.org/10.1016/j.mycres.2007.08.004

Laqbaqbi A., (2020). La truffe entre France et Maroc ou d'un coté à l'autre de la Méditerranée. Imprimerie GRAPHO 12 Aveyron, 80 pages.

Linsley R. K., Kohler M. A., Paulhus J. L. H., (1982). Hydrology for Engineers, 3rd ed., McGraw-Hill, New York.

Malençon G., (1973). Champignons hypogés du Nord de l'Afrique. I. Ascomycètes*. Persoonia - Molecular Phylogeny and Evolution of Fungi,* 7(2), 261–279.

Moreno G., Diez J., Manjon J.L., (2000). Picoa lefebvrei and Tirmania nivea, two are hypogeous fungi from Spain. *Mycol. Res*., 104 (3) : 378-381. https://doi.org/10.1017/S0953756299001227

Olivier J-M, Savignac J-C, Sourzat P., (2018). Truffe et trufficulture. Périgueux : Editions Fanlac. 352p.

Oubrahim H., (2015). Estimation et cartographie du stock de carbone dans l'écosystème de quercus suber de la Maâmora occidentale (cantons a et b) et estimation de son stock d'éléments nutritifs. Thèse de Doctorat, Département Chimie de l'Environnement, Faculté des sciences, Rabat. 202 pages.

Pegler D.N., (2002). Useful fungi of the World: the 'Poor man's truffles of Arabia' and Manna of the Israelites. *Mycologist* (16), pp 8–9. https://doi.org/10.1017/S0269915X02006134

Poffijn A., Berkvens P., Vanmarcke H., Bourgoignie R., (1988). On the Exhalation and Diffusion Characteristics of Concrete. *Radiation Protection Dosimetry* 24 :203-206. https://doi.org/10.1093/oxfordjournals.rpd.a080270

Puliga F., Illice M., Iotti M, Leonardi P., Baghdadi A., Mozafari A.A., Zambonelli A., (2021). True truffle diversity in Iran. *IJM - Italian Journal of Mycology*. 50: 52-6. https://doi.org/10.6092/issn.2531-7342/12822

Robin Ch., Pousse N., Le Tacon F., (2016). Soil characteristics for Tuber aestivum (syn. T. uncinatum). In *A. Zambonelli et al. (eds.), True Truffle (Tuber spp.) in the World, Soil Biology* 47. Pp: 211-231.

Rodriguez A., (2008). Desert truffles. Sur http://www.trufamania.com/desert-truffles.htm.

Serrhini M., El Youssoufi K., Allali K., (1995). Une ressource naturelle exceptionnelle des milieux pastoraux de l'Oriental et du centre Sud Marocain : le « terfèze », situation actuelle et perspectives d'amélioration-. Ecole nationale d'agriculture, Meknès, 33 pages.

Slama A., Fortas Z., Boudabous A., Neffati M., (2010). Cultivation of an edible desert truffle (Terfezia boudieri Chatin). *African Journal of Microbiology Research*. 4(22) : 2350-2356.

Tadja A., (1996). Etude écologique de deux espèces de Terfezia du Sud-Ouest Algérien. Essai de leur mycorhization sur trois espèces céréalières. Magister thesis, National Institute of Agronomy, El-Harrach, Algeria. 57 pages.

Tahiri A., (1997). Relation mycorhizienne entre Helianthemum ledifolium(L) Mill, et des espèces de Terfez du Maroc. Mémoire de troisième cycle en agronomie, Ecole nationale d'agriculture, Meknès, 80 pages.

Trappe J. M., (1979). The orders, families, and genera of hypogeous Ascomycotina (truffles and their relatives) "Clelandia arenacea, Dingleya verrucosa, Choiromyces aboriginum, Peziza stuntzii", new taxa, Fungi. *Mycotaxon* (9), pp 297–340.

Zambonelli A., Donnini D., Rana G.L., Fascetti S., Benucci G.M.N., Iotti M., Morte, A., Khabar, L., Bawadekji, A., Piattoni, F., Compagno, R., Venturella, G., (2014). Hypogeous fungi in Mediterranean maquis, arid and semi-arid forests. *Plant Biosystems*. 148, No. 2, 392–400. https://doi.org/10.1080/11263504.2013.877537

Zitouni F.H., (2016). Etude de la diversité des truffes du désert et de leurs associations mycorhiziennes. Thèse de doctorat. Université d'Oran 1 Ahmed Ben Bella.95 p.

Zitouni F.H., F., Fortas, Z., Chevalier, G., (2014). Morphological characterization of mycorrhizae formed between three Terfezia species (desert truffles) and several Cistaceae and Aleppo pine. *Mycorrhiza*, 24(5) :397-403. https://doi.org/10.1007/s00572-013-0550-7

Zitouni F.H., Zelmat F.Z., (2007). Caractérisation écologique et pédologique de trois sites à terfez de la steppe centrale d'Algérie. Essai de mycorhization de Tirmania pinoyi avec Pinus halepensis en conditions génotoxiques. Mém. Ing. Biotech, Univ. Oran, 62p.