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Kinetics of drying of two edible fungi from Congo: *Termitomyces sp*. and *Oyster mushroom*

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Abstract

On the one hand, an evaluation of three types of drying (oven, microwave oven and solar drying) was used to specify the nature and importance of the unit operation on the characteristic parameters of the various food products. The impact of this process on dimensions, pH and water content were also evaluated. The drying temperature influences these parameters. The dimensions of the mushrooms are reduced after drying, whatever the source of energy. The pH values of fresh and dried mushrooms for Termitomyces sp. are 4.83 ± 0.2 and 4.75 ± 1.2; 4.73 ± 0.9; 4.80 ± 0.7 in the oven; 5.7 ± 0.8 at the solar dryer and 5.26 ± 0.7; 5.3 ± 0.4 in the microwave oven. They range from 5 ± 0.4 to 5.2 ± 0.6; 5.1 ± 0.4; 5.4 ± 0.1 in the oven, 5.6 ± 0.9 in the solar dryer and 5.1 ± 0.7; 5.4 ± 0.5 microwaves, for Oyster mushroom. The pH is globally acidic, indicating a good conservation. The conservation of mushrooms is optimal and compatible with human physiology. The rehydration capacity gives small gaps, however that of Oyster mushroom is high, because of their large dimensions compared to Termitomyces sp. On the other hand, drying characteristics were studied on the water content, in an electric oven at the set temperatures of 50, 60 and 70°C; in a domestic microwave oven with powers of 280 w and 420 w and in a solar dryer. The results indicate that all the experimental curves show an identical appearance: this one is decreasing. The drying time decreases as the temperature and air speed increase. The drying time is 570 and 840 minutes; 430 and 760 minutes; 390 and 590 minutes respectively for Termitomyces sp. and Oyster mushroom, in the case of fungi treated in an oven at temperatures of 50, 60 and 70°C. The drying time varies depending on the temperature. The water content ranges from 83.5 ± 0.4% to 5.06 ± 0.2%; 86, 9 ± 1.4% at 5, 13 ± 0.4%, respectively for Termitomyces sp. And Oyster mushroomat 70°C. The final water content is about 5%.

Keywords: Drying, drying oven, microwave oven, solar dryer, water content, rehydration capacity, hydrogen potential (pH), Congo.

Introduction

The origin of fungal organisms dates well before that of the first plants or animals. It is thus a very old group and, moreover, very rich in species: the estimates oscillate between several hundreds of thousands up to a few millions of different fungal species[1].

Nearly 300 species of wild edible fungi have been identified throughout sub-Saharan Africa[2]. Medicinally, without the fungi we would not have discovered penicillin and we would not have antibiotics to cure us of countless very serious and even fatal diseases. In terms of food, mushrooms are valuable fermentation agents for making cheese, beer and bread with yeast. Some are of great gastronomic value and are rich in protein and vitamins and are therefore of great nutritional value[3].

In nature, fungi feed mainly on dead or inert organic matter which allows rapid decomposition of these. Edible fungi are a very important companion product to African meals, mainly in poor rural areas. While varying the diet, they provide a rich complement of minerals, vitamins and even protein, competing with the best vegetables.

These fungi appear in the rainy season when crops have not yet reached maturity. During this period, they provide another food intake in the country sometimes preceded by the consumption of insects, mainly caterpillars and termites. In this rural context, the nutritional habits as well as the processes of preparation or conservation of these mushrooms are part of an ancestral tradition[4]. In Congo mushrooms grow in all the agro-ecological zones (forest, savannah, plain) and are very consumed by the populations. From North to South, from East to West African populations in general and Congolese in particular appreciate the taste of mushrooms and ease in their culinary preparations. The mushrooms are mostly out at the beginning of the rainy seasons (early October) and the harvest can last two (02) to five (05) months, depending on the type of mushrooms, with a predominance in the first two (02) months.

Mushrooms are therefore an important food source during the boom period, and represent an income-generating activity for men and women, and young people, with a dominance of women. The edible mushrooms of Congo have an interesting nutritional value[5].

Mushrooms are perishable food products that require appropriate conservation technologies. Huge post-harvest losses are recorded each year, thus reducing the efforts of the actors and actresses of the sector, and making their socio-sanitary conditions difficult.

It is with this in mind that we conducted this study using drying as an appropriate technology with major concerns to preserve the quality of products to be compatible with human physiology.

Drying is the oldest means of preservation used by man[6]. It is the most used preservation technique in terms of application methodologies and industrial sector due to the ease and practicality of the operations involved.

The purpose of the drying is to reduce considerably or completely the water present in an initially moist body and to obtain a body capable of being preserved by reducing or stopping the main microbiological, enzymatic reactions[7]. Drying increases the shelf life of products and reduces the weight and volume of products, making shipping easier[8].

The overall objective of this study is to ensure the conservation of mushrooms according to the type of drying used. The specific objectives are pursued: i. drying in the solar dryer, oven and microwave oven; ii. determine the characteristic curves; iii. determine the physicochemical parameters; iv. appreciate the behavior of dried mushrooms.

Materials and methods

Equipment: Plant material: The mushrooms studied *Termitomycessp*. And *Oyster mushroom* (Photo-1 and 2) were purchased at the Total and Bourro markets in the city of Brazzaville.

Photo-1: *Termitomyces sp.*

Photo-2: *Oyster mushroom.*

Laboratory equipment: The drying tests were carried out successively in a solar dryer, in an oven and in a microwave oven.

Characterization of the raw material: The dimensions (length and width and thickness) were determined using Caliper type 0-200x0.02 mm. The mass of a sample was determined using a Gram brand electronic scale, SPX series with an accuracy of 0.01g.

pH study: The measurements of the pH values of the mushrooms were carried out in a suspension of 0.2g/ml of distilled water, that is to say 5g of sample in 25ml of distilled water). The measurement was made using a digital pH-meter (Pocket-Sized) equipped with a combined electrode. Calibration of the apparatus was obtained with pH 4.0 buffer solution at 25°C.

Drying of mushrooms: The drying method has two main stages: the preparation of the mushrooms and the drying itself.

The scheme of the drying process is shown in Figure-1 below.

Mushroom preparation: After reception, the mushrooms are cleaned with a brush to get rid of dust, washed, wiped and leave to rest for about twenty minutes.

Drying: Study of the drying of mushrooms in an oven: 100 g mushrooms are weighed that we have on aluminum foil; place everything on a rack inside the oven. After the oven is turned on, the temperature and the time are set; the oven is switched on. During drying, the successive weighings are carried out every 30 minutes until the mass of the product is stabilized. After cooling in the desiccator, the mushrooms are placed in the plastic pots, labeled and stored on the bench.

Microwave mushroom drying study: We weigh 100 g of mushrooms that we have on a Pyrex petri dish of 12 cm in diameter; all placed on the turntable inside the oven. After the oven is turned on, the specific power and time are set at the selected levels; the oven is then started. During drying, the successive weighings are carried out every 30 seconds until the product is stabilized.

Study of the drying of mushrooms by solar dryer: For each mushroom, a mass of 100 g is taken, deposited on the aluminum paper, all placed on the rack in the drying zone inside the solar dryer. During drying, the successive weighings are carried out every 30 minutes until the product stabilizes.

Air velocity was measured using an airspeed anemometer. Dry mushrooms collected in an oven, solar dryer and microwave are cooled in a desiccator and placed in the labeled pots and stored on the bench until use. Drying was carried out according to Figure-1.

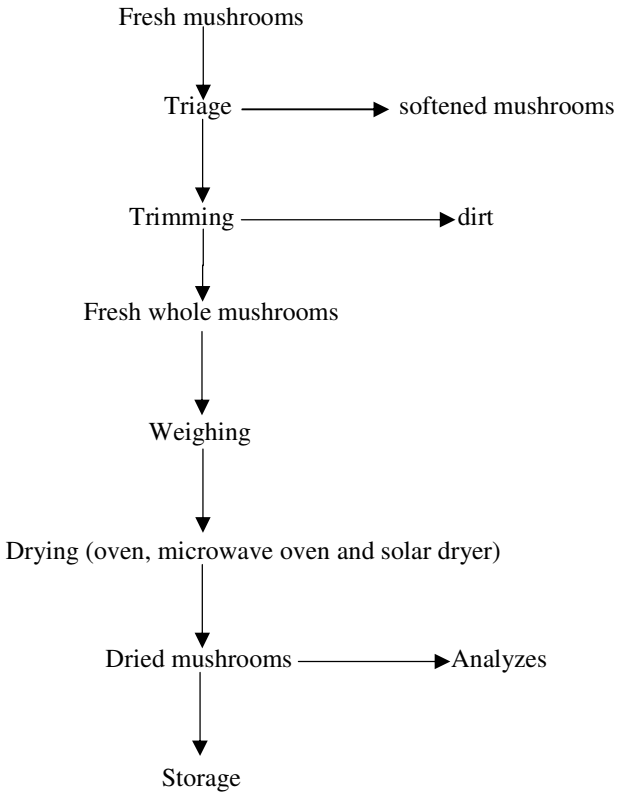

Figure-1: Drying process.

Water content: Dry water content: The determination of the low-dry water content of the samples was carried out mainly according to the AFNOR method (NF-VO3-708). After homogenization of the product, a quantity of 5 g of sample was introduced into a capsule. The capsule was introduced into the oven (Memmert) heated at 105°C. for 24 hours, to a constant weight.

The dry basis water content of the mushrooms being dried has been determined by calculation according to the following formula:

$$X = \frac{M1-M_2}{M_2} \quad (1)$$

Or: X = the dry water content in g of H2O / g MS, M1 = the mass of the test sample before drying in g, M2 = the mass of the test sample after drying in g.

Moisture content in wet base: 5g sample of fresh material were weighed (P) into previously weighed stainless aluminum cups (Pvide), using a Gram brand electronic scale, SPX series with an accuracy of 0.01 g .de accuracy. The sample was allowed to dry at 105°C until the total evaporation of the water in the substrate (Psec).

The wet basis water content of the mushrooms being dried was determined by calculation according to the following formula:

$$X = \frac{M1-M_2}{M1} \quad (2)$$

Or: X = wet basis water content in g H2O / g MS, M1 = the mass of the test sample before drying in g, M2 = the mass of the test sample after drying in g

Rehydration capacity: The sample is placed in distilled water at room temperature of 20°C. The calculation of the rehydration capacity (% H) was expressed as the mass of the water absorbed after 10 minutes immersion, divided by the dried mass of the sample, according to the following formula:

$$\%\,H = \frac{M1-M_2}{M1} \quad (3)$$

% H = Rehydration capacity, M1 = mass absorbed after immersion, M2 = Dry mass of the sample, 2.6. Statistical treatment of data:

The tests carried out were repeated in triplicate. The results obtained are expressed as averages followed by the standard deviation.

Results and discussion

Morphological data of mushrooms: The morphological characteristics of the fungi studied are presented in Table-1.

Legend: B ET: *Termitomyces sp*. dried in the oven, BSSO*: Termitomyces sp*. solar kiln dried, BMI: *Termitomyces sp*. microwave-dried, SAET *Oyster mushroom* dried in the oven, SASSO *Oyster mushrooms* dried by solar dryer, SAMI *Oyster mushrooms* microwave oven dried.

It appears from Table-1 that the dimensions of the mushrooms decrease after drying. The dimensions of *Oyster mushroom*are greater than those of *Termitomyces sp*.

Termitomyces sp. Dried mushrooms on the oven averaged 5.1±0.4; 5.2±0.6 and 5.4±0.3; widths 0.22±0.10; 0.21±0.11 and 0.20±0.11 and thicknesses 0.1±0.01; 0.1±0.01 and 0.1±0.0.

As for *Oystermushrooms* (oven-dried mushrooms) dried in an oven, they have on average lengths of 6.9±0.01; 6.6±0.01 and 6.1±0.0; widths of 5.4±0.2; 5.2±0.2 and 5.0±0.1, thicknesses.

pH data: The pH measurement of fresh and dried mushrooms is given in Table-2.

Table-1: Dimensions of fresh, oven-dried mushrooms, microwave oven and solar dryer (length, width and thickness).

Samples		Dimensions of fresh mushrooms (before drying): average (cm)			Dimensions after drying: average (cm)		
		Length	Width	Thickness	Length	Width	Thickness
BET	50°C 60°C 70 °C	5.8 ± 0.5	0.3 ± 0.1	0.13 ± 0.03	5.1 ± 0.4 5.2 ± 0.6 5.4 ± 0.3	0.22 ± 0.10 0.21 ± 0.11 0.20 ± 0.11	0.1 ± 0.01 0.1 ± 0.01 0.1 ± 0.01
BSSO	-	3.5 ± 0.4	0.4 ± 0.3	0.23 ± 0.02	3.2 ± 0.2	0.23 ± 0.20	0.1± 0.01
BMI	280w 420 w	9.0 ± 0.4	0.58 ± 0.4	0.36 ± 0.02	3.76 ± 0.20 2.52 ± 0.40	0.3 ± 0.2 0.2 ± 0.1	0.21 ± 0.03 0.20 ± 0.01
SAET	50°C 60°C 70 °C	9.1 ± 0.6	7.6 ± 0.3	1.1 ± 0.07	6.9 ± 0.01 6.6 ± 0.01 6.4 ± 0.01	5.4 ± 0.2 5.2 ± 0.2 5.0 ± 0.1	0.60 ± 0.05 0.59 ± 0.04 0.57 ± 0.02
SASSO	-	8,3 ± 0.6	5.8 ± 0.2	0.96 ± 0.40	5.96± 0.50	3.7 ± 0.2	0.76 ± 0.2
SAMI	280 w 420 w	9.20 ± 0.7	2.96 ± 0.50	1.03 ± 0.30	6.76 ± 0.40 6. 1 ± 0. 35	1.80 ±0.20 0.96 ± 0.10	0.66 ± 0.04 0.54 ± 0.03

Table-2: pH values of fungi.

Sample			Average pH
Fresh *Termitomyces sp.*			4.83 ± 0. 2
Dried *Termitomyces sp*. (conserved after a year)	Oven	50°C 60°C 70°C	4.75 ± 1.2 4.73 ± 0.9 4.80 ± 0.7
	Solar dryer	-	5.7 ± 0.8
	Microwave	280 w 420 w	5.26 ± 0.7 5.3 ± 0.4
Fresh *Oyster mushroom*			5 ± 0,4
Dried Oyster mushroom (conserved after a year)	Oven	50°C 60°C 70°C	5.2 ± 0.6 5.1 ± 0.4 5.4 ± 0.1
	Solar dryer	-	5.6 ± 0.9
	Microwave	280 w 420 w	5.1 ± 0.7 5.4 ± 0.5

The analysis of the results in Table-2 shows that the pH values for fresh and dried mushrooms are 4.83±0.2 and 4.75±1.2, respectively; 4.73±0.9; 4.80±0.7 in the oven; 5.7±0.8 at the solar dryer and 5.26±0.7; 5.3±0.4 micro waved for *Termitomyces sp.* For *Oyster mushroom* these values vary by 5±0.4 and 5.2±0.6; 5.1±0.4; 5.4±0.1 in the oven, 5.6±0.9 in the solar dryer and 5.1±0.7; 5.4±0.5 in the microwave oven.

The pH is acidic in both cases (before and after drying): the preservation of the mushrooms after drying is compatible with human physiology.

However, the small pH differences observed after conservation, would be attributable to the development of molds. These results corroborate with those of N'dembé (2015) on edible Termitomyces fungi from Congo.

The same observations are given by Banzouzi (2014) on the drying of palm nut pulp[5,9].

Water content values: Moisture and dry water content values of the mushrooms are given in Table-3.

The wet base water content of *Oyster mushrooms* ranges from 86.5±0.8%; 86.9±1.4% and 87.7±0.6% and that of *Termitomyces sp*. Ranges from 81.1±1.2%, 83.5±0.4% and 82.8±0.5% dried at 50°C, 60°C and 70°C, respectively.

Oyster mushrooms have higher wet base water contents than *Termitomyces sp*. This is due to the larger sizes of *Oyster mushrooms*.

The trend observed is the same for drying in the microwave oven and solar dryer. Okoro and Achuba (2012) working on 5 species of Nigerian fungi (Lentinus squarrosulus, Volvariella volvacea, Coprinus micaceus, Lepiota procera, and Auricularia auricular L) found water contents of 13.01 to 92.02% relative humidity. Adejumo and Awosanya (2005) found water contents of 37% in Termitomyces mammiformis. Visibly, the water content varies with species and experimental conditions[10,11].

Characteristics of the drying of mushrooms: Drying in the oven: Evolution of the water content over time: 50°C, 60°C and 70°C. Figures-2, 3 and 4 below show the curves of the water content over time.

From the analysis of these curves, it firstly results that the content is virtually eliminated after 570 min and 840 min respectively for *Termitomyces sp.* And *Oyster mushrooms*, treated at 50°C.

For mushrooms dried at 60°C these durations are 430 and 760 min respectively for *Termitomyces sp.* And *Oyster mushrooms*. For the mushrooms dried at 70°C these durations are 390 and 590 min respectively *Termitomyces sp.* And *Oyster mushrooms*.

The time required to reduce the initial moisture content (wet base) by 81.10±1.2% at the final water content of 4.29±0.4% (dry basis) is approximately 600 min for *Termitomyces sp*. and 86.5 ± 0.8% at the final water content of 5.40±0.5% is 890 min for *Oyster mushrooms*, for mushrooms dried at 50°C.

These levels vary from 83.5±0.4% to 5.06±0.2% and 86.9%±1.4 to 5.63±1.1% at the 460 min and 790 min times respectively for *Termitomyces* sp. And *Oyster mushrooms* dried at 60°C.

These grades ranged from 82.89±0.5% to 4.81±0.3% and 87.7±0.6% to 5.13±0.4% respectively *Termitomyces sp*. And *Oyster mushrooms* dried at 70°C.

Microwave drying: Evolution of water content over time: 280 W and 420 W. Figures-5 and 6 curves of water content over time at 280 w and 420 w.

Table-3: water content of mushrooms

Parameters	Mushrooms											
	Oyster mushrooms						*Termitomyces sp.*					
	Oven			Solar dryer	Microwave oven		Oven			Solar dryer	Microwave oven	
Wet base water content	50°C	60°C	70°C	Solar radiation	280W	420W	50°C	60°C	70°C	solar radiation	280W	420W
	86.5± 0.8%	86.9± 1.4%	87.7± 0.6%	85 ± 1.1%	88.5± 0.3 %	96.5± 1.2%	81.1± 1.2 %	83.5± 0.4 %	82.89± 0.5%	82± 1.2 %	78± 0.3%	76.5± 0.3 %
Dried base water content	5.40± 0.5%	5.63± 1.5%	5.13± 0.4%	5.66± 0.7 %	7.69± 0.2 %	4.26± 0.41%	4.29± 0.4 %	5.06+ 0.2 %	4.81± 0.3%	4.55± 0.5 %	3.54± 0.5%	3.25± 0.5 %

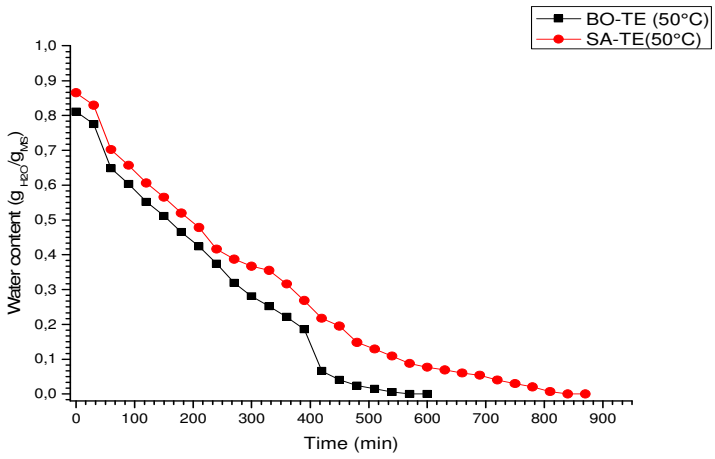

Figure-2: Evolution of the water content over time (50°C).

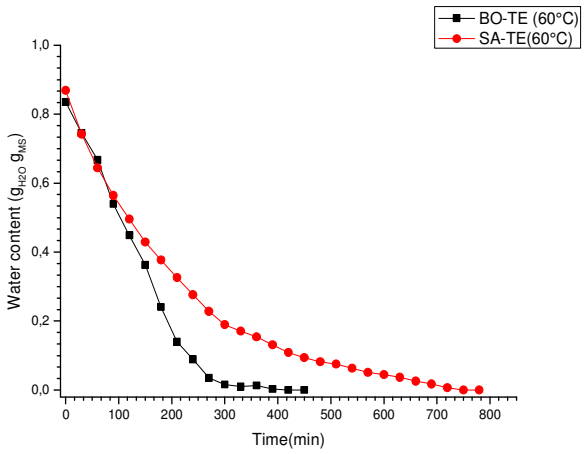

Figure-3: Evolution of water content over time (60°C).

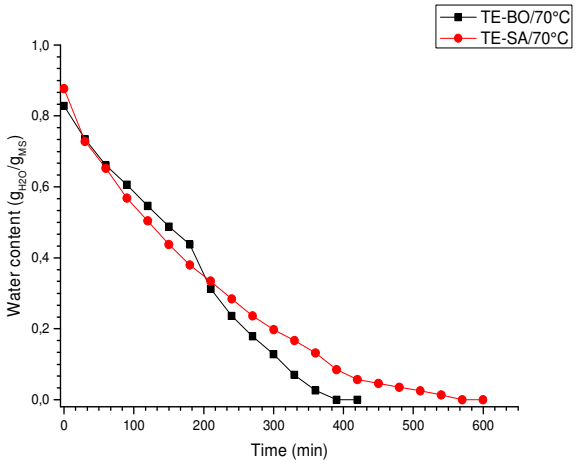

Figure-4: Evolution of the water content (70°C).

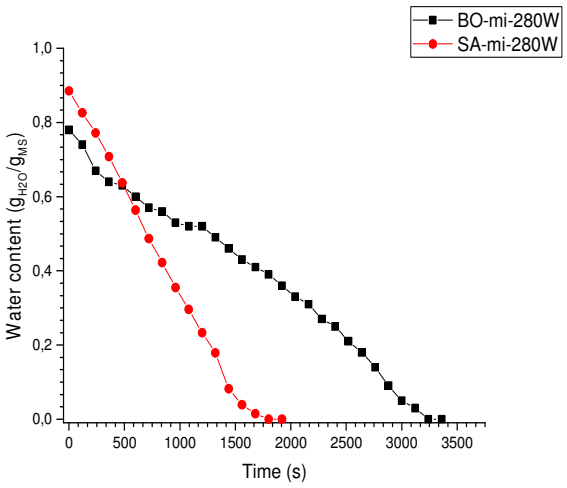

Figure-5: Evolution of water content over time (P = 280W).

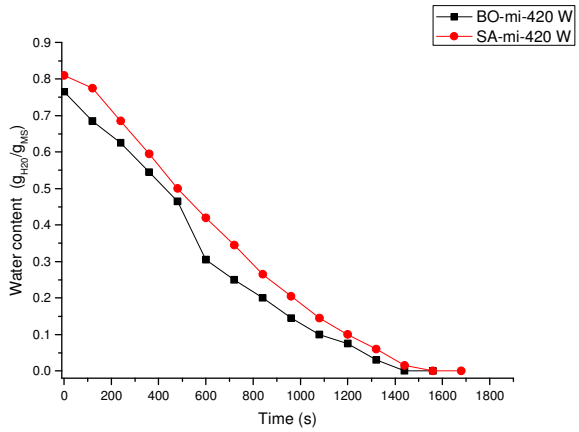

Figure-6: Evolution of water content over time (P = 420 W).

The water content is practically zero after 3240 and 1800 secs respectively for *Termitomyces sp*. And *Oyster mushrooms* treated at 280 W.

For mushrooms dried at 420 W these durations are 1440 and 1560 secs respectively for *Termitomyces sp.* And *Oyster mushrooms*.

The time required to reduce the initial water content (wet basis) from 78±0.3% to the final water content of 3.54±0.5% (dry basis) is approximately 3240 secs for *Termitomyces sp*. and 88.5±0.3% at the final water content of 7.69±0.2% is 1920 dry for *Oyster mushrooms*, for mushrooms dried at 280W.

These grades range from 76.5±0.3% at 3.25±0.5% and 96.5±1.2% at 4.26±0.41% at the dry times of 1440 and 1560 respectively for *Termitomyces sp*. and *Oyster mushrooms* dried at 420 W.

Drying with a solar dryer: Evolution of water content over time at the solar dryer. Figure-7 shows curves of water content over time.

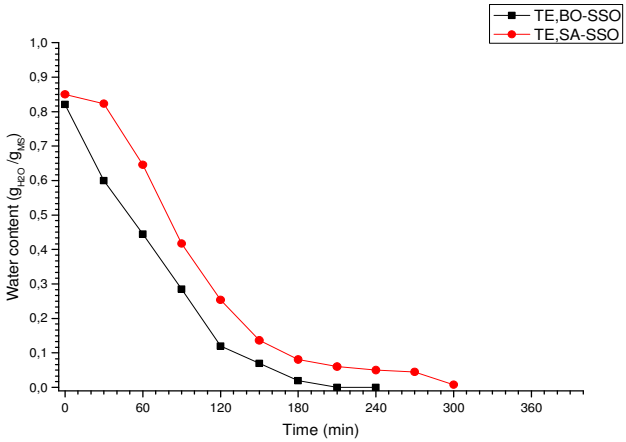

Figure-7: Evolution of water content as a function of time.

The water content is practically zero after 240 minutes 330 minutes respectively for *Termitomyces sp*. And *Oyster mushrooms* in the solar dryer.

The average temperature during drying is 39.18°C. The average air speed of 1.40m/s.

The drying time depends on the temperature (solar radiation) and the air speed. The time required to reduce the initial moisture content (wet base) from 82±1.2% to the final water content of 4.55±1.2% (dry basis) is approximately 240 min for *Termitomyces sp.* and 85±1.1% at the final water content of 5.66±0.7% is 360 min for *Oyster mushrooms*, for solar kiln dried mushrooms.

Thus, the higher the temperature in the oven, the shorter the drying time for the mushrooms. In addition, the small size of the mushrooms increases linearly the drying rate. The effect of small size is much greater at high temperature than at low temperature. These results are similar to those described in the literature on other products, Safous(*Dacryodesedulis*)[12,13].

The experimental curves show an identical appearance; it is decreasing. The absence of the phases of heating (phase o) and drying at constant rate (phase 1) is noted. Only the phase with decreasing rate (phase 2) is present. The same results were found for other plants by authors such as[14-17].

In general, the time required to reduce the moisture content at any level depends only on the drying conditions.
Drying during the decaying phase is governed by the diffusion of water into the solid. It is a complex mechanism involving water in both liquid and vapor states, which is often characterized by effective diffusion. This property depends on the temperature, the pressure and the water content of the product[18,19].

Thus, the higher the power in the microwave oven, the shorter the drying time for the mushrooms. In addition, the small size of the mushrooms increases linearly the drying rate. The effect of small size is much greater at high temperature than at low temperature.

The experimental curves show an identical appearance; it is decreasing. The absence of the phases of temperature (phase o) and drying at constant rate (phase 1). Only the phase with decreasing rate (phase 2) is present.

During solar drying, fungi lose water and therefore these products receive more heat. The loss of mass is a function of the drying mode and the temperature applied. These curves have the same speeds as those described byDesmorieux[20]. The variation in drying time is a function of temperature, which is explained by the fact that the increase in temperature causes an increase in the intensity of the heat transfer. Similar observations have been reported by Igwe and Njomo[21,22]. Drying in an oven and solar drying are faster than drying in the open air. This is due to the fact that during the experiment the average dry season temperatures were low and the wind played in favor of open air drying.

Rehydration capacity: The values of the rehydration capacity are given in Table-4.

The values in Table-4 state the rehydration capacity of our samples of the fungi studied. These values indicate that the rehydration capacity varies from 41, 24 ± 0.5% to 50.48 ± 0.98% for *Termitomyces sp.*

For *Oyster mushrooms* these values range from 55.74 ± 0.48% to 71.54 ± 0.19%. These values show a good behavior of dried mushrooms to rehydrate easily, with values of more than 40%. However, these values are higher for *Oyster mushrooms* and lower for *Termitomyces sp*. This can be explained by important dimensions for *Oyster mushrooms*. These results are consistent with those given by Albitar[7].

Conclusion

This work reveals the dimensions of *Oyster mushrooms*are larger than those of *Termitomyces sp*. Similarly, the water content and rehydration capacity of*Oyster mushrooms*is higher than that of *Termitomyces sp*. Applied drying technologies show good fungal conservation, compatible with human physiology, with pH values that are acidic. The drying time is shorter for *Termitomyces sp*. And longer for *Oyster mushrooms*. This time is shorter as the power or the experimental temperature is strong.

In addition, this study allowed us to better optimize the three types of drying (oven drying, microwave oven drying and solar drying). The solar dryer is therefore an alternative because of the free solar radiation to overcome traditional deficiencies and obtain better quality products that meet the requirements of modern urban consumers.

Table-4: Rehydration capacity of the fungi studied.

Sample	BSSO	BET			BMI		SASSO	SAET			SAMI	
temperature/ source of radiation	Solar radiation	50°C	60°C	70°C	280W	420 W	Solar radiation	50°C	60°C	70°C	280W	420W
Capacity of rehydration (%)	42.51± 1.32	41.24± 0.5	49.99± 1.00	43.74± 0.78	50.48± 0.98	47.4± 0.38	71.54± 0.19	58.84± .38	60.10± 0.48	57. 75± 1.4	55.74 ± 0.48	59.08 ± 0.6

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