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RESEARCH ARTICLE

CONTRIBUTION TO THE VALORIZATION OF THE LEAVES OF CASSAVA (Manihotglaziovii), CULTIVATED IN THE CITY OF BRAZZAVILLE (CONGO) BY THE DRYING PROCESS

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ABSTRACT

The aim of this work is the study of the influence of different drying methods (open air, oven) on the kinetics of drying process of cassava (Manihotglaziovii) leaves. Regardless of temperature and the method of drying, the change in mass follows an identical development, the curves of the moisture content based on the time have an identical look. Five empirical models were used for the kinetics of drying. The templates that match best kinetics of drying of the leaves of cassava are the model of Wang and Singh followed the Page template. The apparent diffusion coefficient has been determined based on Fick's diffusion model and physicochemical characterization shows that drying has no influence on the physicochemical characteristics of the leaves of cassava.

Key words: Manihotglaziovii, Drying, Open air, Oven, Kinetics, Modelling.

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INTRODUCTION

In many tropical areas, potential food sources exist but are badly exploited due to lack of means of preservation. In Congo, cassava culture occupies an important place in the production of food crops. It strongly participates in the basic food for the majority of people or livestock. Its leaves rich in proteins and vitamins (A and C) are one of the most consumed vegetable in human food dishes in Congo. Its abundance during hot periods leads to substantial losses after harvest. Indeed, these losses can amount to more than 25% but can be reduced by a mode of conservation (Clément Ahouannou *et al.,* 2000; Chakraverty, 2003), such as drying process.The drying of food products is an appropriate way to curb these losses and expand consumption in non-production periods.

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This process also facilitates the transport of food to urban areas and even exportation to foreign countries (Clément Ahouannou *et al.,* 2000; Fournier, 2003). Drying is widely used in the food industry, but handmade by Congolese farmers. This process which allows to stabilize the product by lowering the activity of the water (Iglesias and Cherife, 1982), must respect a certain number of criteria of quality of the product. And the kinetics of this agricultural product forecasting is essential for the design of a type drying system to the product and to determine the optimal conditions of this operation (Daudin and Bimbenet, 1982). Native to the West Indies and Brazil, cassava was introduced into Africa by Portuguese navigators in the 17th century, it grew rapidly in the center of Africa and currently, cassava is grown as annual in tropical countries and subtropical America, Africa and Asia (Aufret, 1957). The type *Manihot*, of the family of *Euphorbiaceae*, includes more than 100 species with the same chromosome number (2n-36 chromosomes). It is divided into 98 species (Sylvestre and Arraudeau, 1983), of which the most common are: i)- *Manihotesculenta Grantz* (synonym *Manihotutilisima Pohl*):

the most widely grown in the world because of its root (tuber) edible which is largely used in industry; ii)- *Manihotglaziovii*: cultivated for its rubber properties, but also thanks to its good climate and biotic stress resistance, it served in the breeding of the cassava (by interspecific crosses) (Memento of the agronomist, 2002). It is the most consumed species in Congo because it is grown even in the city. It does not have tuberous roots.

Chemical composition of cassava leaves

Fresh cassava leaves are a food rich in proteins and vitamins, especially vitamins A and C (Busson F.et Bergeret B.). Raw cassava leaves contain also considerably more energy, protein, fat, carbohydrate, fibre, ash, minerals (Ca, P, Fe, etc.), vitamin A, thiamine, riboflavin and niacin than some vegetables introduced, such as Chinese cabbage or spinach (IITA, 1990).

The drying process

Drying is a unit operation designed to eliminate partially or totally water from a wet body (produced) by evaporation of this water (Charreau, 1991). The latter can be solid or liquid, but the final product is solid except in the specific case of dehydration of a nonvolatile liquid: drying of oils (Bimdenet, 1984). It was noted that, during the drying process, the water contained in the material disappears little by little in the air under the action of two phenomena: the evaporation of water and its distribution within the material (Keachou, 2000). Drying is an operation of coupled heat and mass transfer for which it is necessary to provide energy. Several types of dryers and drying methods have been adapted to different situations. The operating parameters of the conventional processes of drying can be easily controlled. These so-called conventional methods are drying in the Sun, solar drying and drying with hot air. These are most commonly used for fruit and vegetables (Mounir *et al.,* 2014).

Mathematical formulation

Modeling of drying curves is generally to develop a function checking the following equation: X * = f (t). And since during the drying of a product, a complexity of phenomena occurs, thus several authors have proposed mathematical models (Midilli *et al.,* 2002; Erbay et Icier, 2010) in the form of relationship empirical or semi-empirical to describe drying curves. These models contain constants which are adjusted to match the theoretical results with experimental drying curves. And they have been proposed by Zhengfu Wang and al., table 1. Indeed the final water content is a feature of each product. This is the optimal value for which the product is not deteriorating and keeps nutritional and organoleptic qualities (shape, texture, color, smell, and essential oils) (Kouhila, 2001). The principle of the method developed by Van Meel (1958) is a standardization representing the drying speed report in a time t:

$$X^* = \frac{X_t - X_e}{X_{cri} - X_e} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

As the first phase is absent in the case of food products, we take:

$$\left[-\frac{dX}{dt}\right]_1 = \left[-\frac{dX}{dt}\right]_0 \text{and } X_{cri} = X_0. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

So the general formula of the reduced water content is[21]:

$$X^* = \frac{X_t - X_e}{X_{cri} - X_e} = \frac{X_t - X_e}{X_0 - X_e} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

With :X_e : Balancing water content (%DM : dry mater)
X_0: initial water content
X_{cri}: critical water content

Drying should be done knowing the purpose pursued in order not to destroy the raw material, also we conducted physicochemical analyses on dried cassava leaves by the two methods chosen in order to see if there has been tampering of the nutritional value of these leaves during drying.

MATERIALS AND METHODS

Materials

The vegetable material used is consisted of the cassava leaves of the species *Manihotglaziovii*, cultivated in the city of Brazzaville. The choice of this variety is justified by its abundance on the national market and its taste quality appreciated by the consumer. Drying is intended to eliminate any water present in the leaves. For this we used the oven (oven maxi 70°C DHP-9052) at a temperature of 50, 60 and 70°C for a mass of 100 g of crushed at the start. A mass of 100 g of crushed was used similarly in the open air to the departure and drying is made for 8 h at temperatures ranging from 29.7 and 32.2 °C, with air an average of HR = 51.2% relative humidity, air speed varying between 0.9 m/s and 1.6 m s, measures taken by the following devices: Thermo-anemometer Lafayette A-M-Flex for the temperature and the air speed and Hygrotermometre RF Remote Sensor. INOVALLLEY model 001 H 32 for the relative humidity of the air. Electronic balance, precision 0.01 g, Electronic Scale G & G T1500 enabled us to follow the change in the mass of the product continuously.

Methods

Transformation Process

The leaves were separated from their stalks, washed, blanched (soaked in a bath of boiling water for 15 minutes) and then crushed with a pestle and mortar. After being crushed, a quantity was weighed and then dried. The transformation process of fresh cassava leaves into dry cassava leaves is presented according to the following diagram (Figure 1):

N.B: blanching (Louembe *et al.,* 2003; Ferradji *et al,* 2001; Doymaz, 2004b; Abdelhak and Labuza, 1987) is very important in this transformation because its goal is:

i. To destroy a large part of the microorganisms in the leaves;
ii. To make leaves cells more permeable which will facilitate the elimination of water during the drying process; iii)- to slow down the degradation of these leaves, especially color and nutrition;
iii. To eliminate cyanogeniques glucosides which concentrations vary from 1000 to 2000 $mg.kg^{-1}$ in dry weight.

Kinetics of drying

To draw our kinetics we needed different masses of the product subject to dry at all times.

Table 1. Mathematical models given by various authors for the curves of drying (*Zhengfu Wang and Al, 2007*)

N°	Model name	Model expression	*Equation for determination of coefficients*
1	Lewis (Bruce (1985))	$X^* = \exp(-kt)$	$lnX^* = -kt$
2	Page (Page (1949))	$X^* = \exp(-k\,t^n)$	$lnX^* = -kt^n$ $\ln(-lnX^*) = \ln(k) + nln(t)$
3	Henderson and Pabis (1961)	$X^* = a.\exp(-kt)$	$lnX^* = \ln(a) - kt$
4	Wang and Singh (1978)	$X^* = 1 + at + bt^2$	
5	Diffusion of Fick (Diamante and Munro (1991))	$X^* = a.\exp\left(-c.\left(\frac{t}{L^2}\right)\right)$	$lnX^* = \ln(a) - \left[-\frac{\pi^2 D_{eff}}{4L^2}\right]t$

With: X*: Reduced water content; n: Number of model constants; Xeq: Equilibrium water content (%DM: dry mater); Deff: Effective diffusivity ($m^2.s^{-1}$); t: Drying time (min); a,b,c,k: Coefficients of the models.

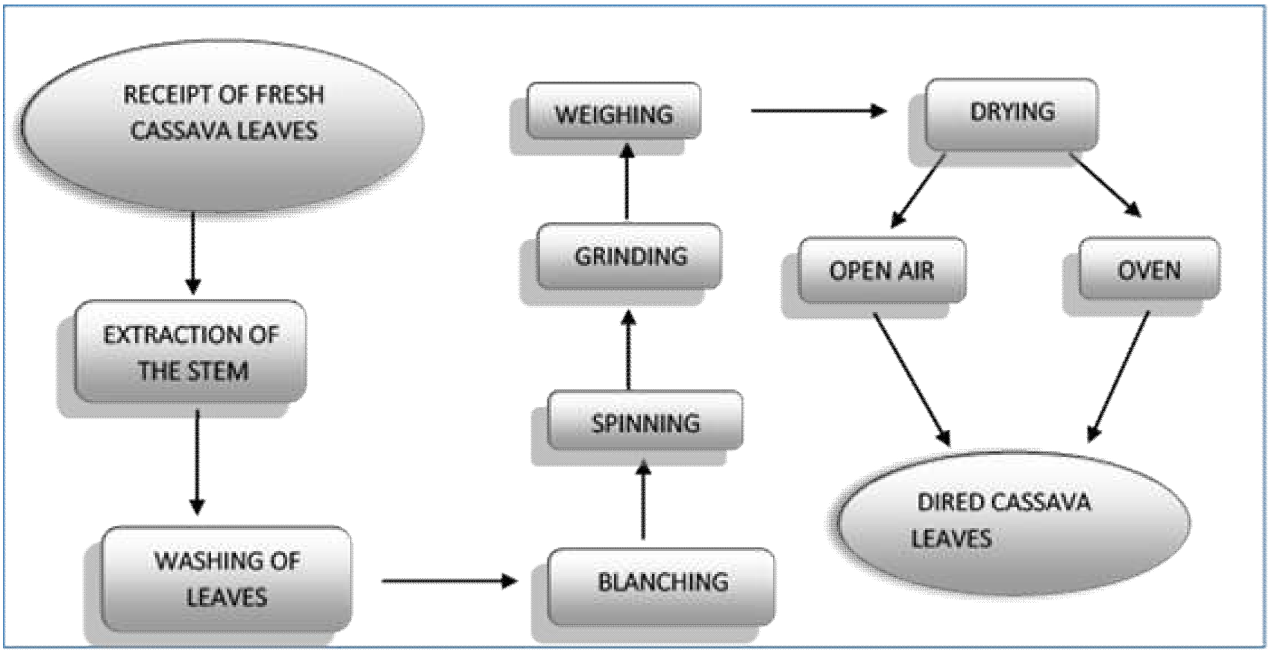

Figure 1.Diagram of the process of transformation of fresh cassava leaves into dry cassava leaves

The principle is simple, as the wet goods beforehand weighed (m_0 = 100 g) is subject to drying in the oven or in the open air, the latter is weighed at 1 hour intervals. The first mass after 1 h is m_1, the second m_2 and so on until the stability of the mass. This stability means that the water evaporates more and so that the product has become dry.

And once all the masses obtained, we can trace all the kinetics of drying curves based on the drying time.

Drying curves

Drying curves show variations in moisture in dry basis X according to the formula (1) according to time:

$$X = \frac{m - MS}{MS} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

With :

X : water content dry basis (Kg water/Kg of dry matter = MS)
m : product mass in g
MS : mass of dry material (MS = total mass of departure - water mass of departure (calculated from the moisture in wet basis)).

Speed of drying

The speed of drying time t is defined according to the following formula:

$$-\frac{dX}{dt} = \frac{-(X(t+\Delta t) - X(t))}{\Delta t} \quad \ldots\ldots\ldots\ldots (5)$$

-dX/dt: drying rate in Kg water/Kg MS / h
X: moisture dry basis (Kg of water/Kg of MS)
Δt : gap of time (in sec, min or h)

Determination of the apparent diffusion coefficient

According to the Fick's diffusion model we have:

$$LnX^* = lna - \left[-\frac{\pi^2 D_{eff}}{4L^2}\right]t \quad \ldots\ldots\ldots\ldots (6)$$

that is a straight line of slope = $\left[\frac{\pi^2 D_{eff}}{4L^2}\right]$

$$D_{eff} = \frac{pente \times 4L^2}{\pi^2} \quad \ldots\ldots\ldots\ldots (7)$$

With L: Thickness average halfway up the sheet of cassava.

Modeling of drying curves

We used the models proposed by Zhengfu Wang *et al.* The model suitable for the description of the appearance of the kinetics of drying of the cassava leaves will be chosen according to the high coefficient of correlation (R^2) (Meziane, 2013).

Physico-chemical characteristics:

- The moisture content is determined by the AOAC method, in an oven under vacuum (AOAC, 1990)
- Rate of ash and minerals (NF T 76-110 sept. 1981). These analysis are made after calcination of the dry product in an oven mitten (600 ° C) for 15 hours. The content in Na, P, Mg, K, and Ca is determined using an atomic absorption spectrophotometer (model 703, Perkin Elmer, USA).
- The fat content is determined to assess the amount of fat present in the dry product. It is done by extraction and the method used is the Soxhlet extraction (Horowitz, 1984)
- The amount of protein is obtained by the method Kjeldahl (total nitrogen dosage) of the AOAC standard, 1984.
- Carbohydrate represents the present rate of carbohydrates in our product dry, it is determined by difference according to the following formula:

$$\%Glucide = 100 - (\%protéine + \%lipide + \%cendres) \ldots\ldots (8)$$

RESULTS AND DISCUSSION

Kinetics of drying of cassava leaves

Evolution of the mass of cassava leaves over time: The evolution of the mass of cassava leaves, depending on the time after temperatures (50, 60 and 70 °C) the oven and in the open air is represented in figure 2

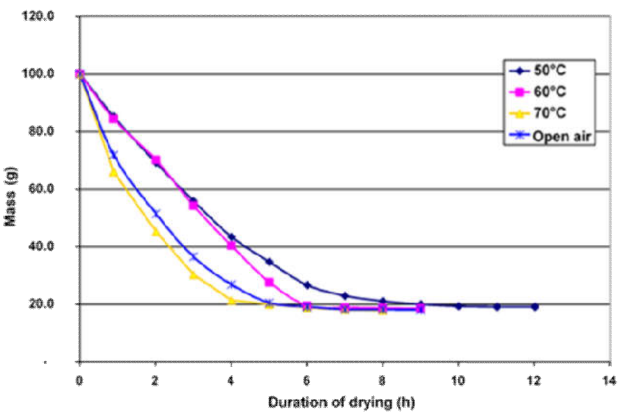

Fig. 2. Evolution of the mass of cassava leaves over time.

The drying time is the time required to dry a product until you reach the final moisture content to a drying temperature less than or equal to the maximum temperature tolerated by the product. Regardless of the temperature and the method of drying, the change in mass follows an identical development. And we got the following drying time: 12 h, 9 h and 8 h for 50, 60 and 70^{0}C the oven temperatures and 9 in the open air. In reality, the mass becomes practically constant after 8 h, 6 h and 4 h at 50, 60 and 70^{0}C the oven and 5 hours in the open air at temperatures varying between 29.7 and 35.2^{0}C and speeds of the air ranging from 0.8 to 1.6 m/s. Starting out from the same quantities of material of fresh samples, we can see that water loss increases quickly when we raise the temperature and thus the rise in temperature caused an increase in the intensity of the heat transfer. The following authors (Ndukwu, 2009; Kulshreshtha *et al.,* 2009; Doymaz, 2005; Krokida *et al.,* 2003; Seiiedlou *et al.,* 2010; Lemus-Mondaca *et al.,* 2009; Panchariyaet al., 2002) also found that the drying time decreased with the increase of the drying temperature.

Drying curves

Drying curves (figure 3) show variations in moisture in dry basis X.

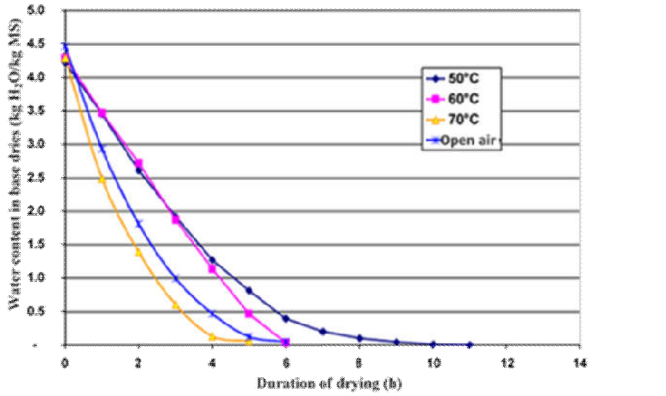

Fig. 3. Evolution of the water content of cassava leaves as a function of time.

The curves of the moisture content based on the time present the same look. At the beginning of the drying more precisely after the first 5 hours curves present linear part of important slope, which corresponds to a rapid water loss. And we see well that water loss is especially fast in the open air at the incubator, for temperatures of 50 and 60^{0}C. When cassava leaves, receive heat, they lose water not linked, it follows a free water surface evaporation in the product. During this period, the product remains outside the hygroscopic field and the water activity a_w in surface is close to 1. Thus we can define experimentally on figure Xcr of cassava leaves critical water content:

- For 50°C drying in the incubator, Xcr = 4.22 Kg water/kg of MS
- for 60°C drying oven, Xcr = 4,30 Kg of water/kg of MS
- for 70°C drying oven, Xcr = 4.29 Kg of water/kg of MS
- for 30-35 ° C drying in the open air Xcr = 4,46 kg / kg water Ms

These values read directly on the curve include significant uncertainties (manual weighings), overall it is arguable that the Xcr for cassava leaves is around 4.3 the oven and 4.5 in the open air. The slopes of the curves tend to soften, the drying speed decreases until you reach a plateau. This phenomenon allows to observe the difficulty of extracting increasingly inaccessible water: bound water.

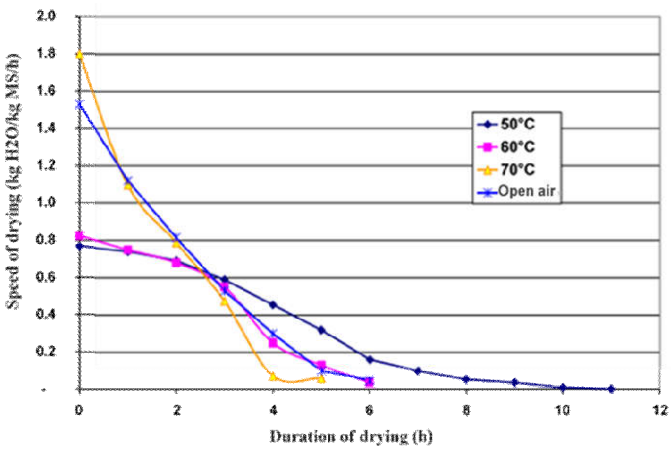

Fig. 4: Drying kinetics of cassava leaves as a function of drying time

The water activity a_w on the surface of the product is less than 1, and internal transfers of materials become limiting. Thus, the temperature of the product tends to increase from the surface. The water content of the product decreases until you reach the bound water Xe content that depends on air drying. Figure 4 shows the curves of kinetics of drying of the leaves of cassava according to time. The principle of the characteristic drying curve is to reduce all experimental data so that you can put them in useable not only by the experimenter form itself, but also by the entire scientific community (Van Mell, 1958). To achieve this, the approach consists of a normalization, representing the drying speed report at a time t (-dx/dt) at the speed of first phase (-dx/dt)i, under the same conditions of air based on moisture content reduced (Kouhila 2001; Kechaou, 2000). All these kinetics curves decrease but with different speeds. It is observed that 70^0C and the open air departure speeds are 1.54 and 1.8, to 60 and 50 ^{0}C these speeds are of 0.83 and 0.77.

Table 2. Statistical results of selected models

N°	T (°C)	k	n	a	b	R^2
1	50 °C	0.4774				0.8842
	60 °C	0.3730				0.8574
	70 °C	0.8434				0.8464
	Open air	0.6645				0.8683
2	50 °C	0.8367	0.3470			0.9496
	60 °C	0.1377	0.5803			0.9912
	70 °C	0.2949	0.6559			0.9980
	Open air	0.8683	0.5451			0.9886
3	50 °C	-0.6207		2.7281		0.9486
	60 °C	-0.5041		1.6172		0.9352
	70 °C	-1.1453		2.4741		0.9234
	Open air	-0.8694		2.1197		0.9316
4	50 °C			-0.2270	0.0127	0.9989
	60 °C			-0.1980	0.0034	0.9996
	70 °C			-0.4411	0.05	0.9984
	Open air			-0.3611	0.0335	0.9994
5	50 °C			2.7281		0.9486
	60 °C			1.6172		0.9352
	70 °C			2.4741		0.9234
	Open air			2.1197		0.9316

a,b,c,k,n: Coefficients of the models used ; R^2: Coefficient of correlation

Modeling of drying curves of the cassava leaves

As the criterion of a good model is the value of the correlation coefficient, which is close to 1, we notice that:

- The Page template is to consider especially at temperatures between 60 and 70°C as in the case of the pulps of Safou (Massamba *et al.,* 2012). We also see the same results in the case of drying in the open air.
- Lewis, Henderson and Pabis and dissemination of Fick models give us unconvincing results.

This means that the speed of drying in the oven decreases with decreasing temperature. However, although the temperature outdoors (29-35^0C) is less than 50 and 60^0C, the drying rate is higher outdoors than the latter because of the speed of exchange of material between the product and the hot, dry air. Indeed in the open air it has a speed of air in the range of 0.9 to 1.5 m/s while in the oven we do not have a circulation of air and we know that the speed of drying increases with the airflow (Doymaz, 2004a; Duzzioni and al. 2013). From what precedes, we see that the model that matches the best kinetics of drying of cassava leaves, is the model of Wang and Singh ($X^* = 1+at+bt^2$), because, with this model we have the coefficients of correlation close to 1 regardless of the drying mode. The right temperature of drying the oven being 60 ^{0}C followed the drying in the open air. The results of the calculation of diffusion coefficients are reported in table 3.

Table 3. Value of the coefficient of diffusivity based on the drying temperature

Drying method	Drying temperature	Diffusion coefficient ($m^2.s^{-1}$x10^{-7})
Oven	50 °C	4.6
	60 °C	5.6
	70 °C	10.4
Open air	30 - 35°C	7.9

Diffusivity coefficient values range between 4,6 and 10, 4 x 10^{-7} $m^2.s^{-1}$. They vary depending on the temperature, which brings us to think of the resistivity in surface created by a kind of rind.

Physicochemical characterization of cassava leaves (*Manihotglaziovii*)

The results of the physicochemical characterization of the fresh and dry cassava leaves are represented in table 4 below

We notice that the dried cassava (*Manihotglaziovii*) leaves have a moisture content between 0.2 and 0.4%, which means that our product is very dry compared to the water content of departure which is 72.5%. And from these low levels in water, bacteria, fungi, yeasts and moulds may develop to deteriorate the product(Labuza, 1975). With about 29% of protein and 59% of glucids it shows that even in the dry state, cassava leaves are always high in protein and high-energy compared to fresh. Their near 5% ash content translates that these dried leaves also contain enough minerals. We can therefore conclude that the drying has no influence on the physical and chemical qualities of cassava leaves. In order to confirm our results, we suggested to compare them to those of Busson and Bergeret.

Table 4. Chemical composition of dried and fresh cassava leaves (*Manihotglaziovii*).

Components	Fresh cassavaleaves	dried cassava leaves (oven 50°C)	dried cassava leaves (open air)
Water (%)	72.5±0.7	0.4±0.03	0.2±0.93
Carbohydrates (%)	15.84±0.9	58.6±1.18	58.1±1.08
Proteins (%)	7.73±1.53	28.6±3.38	29.0±2.03
Lipids (%)	2.4±2.03	7.9±1.67	8.1±1.09
Ashes (%)	1.33±0.02	4.8±0.43	4.9±0.08
Calcium (mg/100 g of product)	5.56±3.19	22.6±1.98	19.2±4.05
Phosphorus (mg/100g of product)	2.58±0.97	31.8±0.98	27.7±1.54
Iron (mg/100 g of product)	0.14±1.02	0.56±1,75	0.36±2.09
Magnesium (mg/100 g of product)	2.8±0.02	5.4±0.17	5±0.05
Potassium (mg/100 g of product)	4.2±1.27	17.6±0.98	18±0.91
Sodium (mg/100 g of product)	0.06±0.57	0.2±0.19	0.22±0.08

%: percent

We find that there is not enough difference except at the level of minerals where there is a slight difference, certainly due to the quality of the soils of culture or the species; but it should also be noted that these results are old.

Conclusion

The contribution to the development of cassava leaves by drying for the case of the species *Manihotglaziovii* revealed that drying is very appropriate for cassava leaves conservation whether in the oven or in the open air. Dry, these cassava leaves do not lose their nutritional value, but are rather high in protein (28.6%) and glucids (58.6%) than when they are fresh.

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