International Research Journal of Environmental Sciences ISSN 2319–1414
Vol. **9(2),** 28-37, April **(2020)** *Int. Res. J. Environmental Sci.*

Study of the traditional solar drying of six cassava varieties grown in Côte d'Ivoire

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Available online at: www.isca.in, www.isca.me
Received 2nd August 2019, revised 5th February 2020, accepted 1st March 2020

Abstract

This work is original in characterizing the traditional solar drying of six cassava varieties (Akaman, Bocou, Bonoua, Manioc blanc, Yacé and Yavo) grown intensely in Côte d'Ivoire. In its implementation, the drying kinetic of these cassava varieties was monitored over a week. Known mass of these cassava samples were dried directly in the sun on an aluminum support. The measurements of sample temperatures, those of the ambient air and the aluminum support, as well as the weighing of these samples, were carried out at well-defined time intervals. From results obtained, it appears that all drying curves of these cassava varieties have a decreasing algorithmic appearance. The moisture for all these cassava varieties, less than 3% of their initial moisture, was obtained after seven consecutive drying days. Their critical moisture (between 0.923 and 1.322 g/g dry matter) is relatively important. This is also the case for their mean vaporization enthalpy (between 8.19×10^6 and 1.72 kWh/kg), mean heat transfer coefficient (between 334.20 and 340.88 $W.m^2/°C$), mean overall diffusion resistance to water vapor (between 4106.17 and 5408.96 m^2s/kg) and mean mass transfer coefficient (between 1.09×10^{-4} and 1.50×10^{-4} kg/m^2sbar).

Keywords: Agricultural products**,** Cassava, Côte d'Ivoire, Drying characteristics, Traditional solar drying, Thermal drying.

Introduction

The drying of plants is one of the important processes for their conservation and processing. So, several techniques, more and more efficient, are constantly being implemented. Among them, there is solar drying. This drying technique has been the subject of numerous scientific studies since first works done by Lewis[1] and Sherwood[2]. At present, these studies are devoted to the realization of innovative or modern solar dryers, such as solar ovens[3,4], solar greenhouse drying[5,6], hybrid solar dryers[7,8]. However, the traditional solar drying remains the most widely used technique, especially in developing countries[9-11]. This fact lies in its easy implementation and its low cost. Indeed, the traditional solar drying consists to bring directly to the sun contact products to dry without prior protection. One of agricultural products subject to this type of drying is cassava. Scientifically known as *Manihot esculenta* or *Manihot esculenta Crantz*, cassava is grown in many varieties in all humid tropics of the world. Its global production in 2017 is 291,992,645 tons, of which 5,367,000 tons are from Côte d'Ivoire[12]. This makes cassava one of the top three sources of polysaccharides, with yam and breadfruit in tropical countries[13,14]. Studies relating to its solar drying using innovative or modern solar dryers are numerous and continuously developed such as those carried out by Koua et al.[15], Tieu et al.[16] and Yahya et al.[17]. However, these studies only refer to one variety of cassava, which is generally undefined. Also, studies concerning characteristics of the traditional solar drying of cassava are very little provided in the literature. Therefore, it is important to conduct in-depth studies on the traditional solar drying of a number of cassava varieties. It is in this context that this study was conducted. Its general objective is to characterize the traditional solar drying of six cassava varieties, the most grown in Côte d'Ivoire.

Material and methods

Collection, conservation and treatment of samples: Six cassava varieties, grown intensely in Côte d'Ivoire, were used in this study. These varieties are Akaman, Bocou, Bonoua, Manioc blanc, Yacé and Yavo. Of all these varieties, only Yacé is in the category of "bitter cassava". The others are in category "sweet cassava". These varieties were collected on a local market (the wholesale market of Yopougon-Siporex (Abidajn-Côte d'Ivoire) during their unloading, after their harvest the day before in several cities of Côte d'Ivoire.

The collection, preservation and treatment of tubers of these six cassava varieties were carried out within 48 hours after harvest, as recommended by Akpingny et al[18]. Thus, after collection in this market, the samples of these tubers were sent to the laboratory and then stored at 4°C in the refrigerator. The next day, they were peeled to recover their flesh. Each tuber flesh was cut into a cylindrical shape with an average thickness of 2 cm and an average base radius varying from one variety to another (between 1.8 and 2cm). These cylindrical shapes were then reduced to quarter-cylinder shaped. The initial moisture of each sample was obtained by the gravimetric method according to the AFNOR NF P94-050 standard[19]. The initial characteristics of these samples are given in Table-1.

Table-1: Initial characteristics of the samples of the six cassava varieties used in this study.

Cassava variety	Initial mass (g)	Mean contact area (cm^2)	Mean Volume (cm^3)	Mean density (g/cm^3)	Initial moisture (g/100 g of dry matter)
Yavo	156.05±0.01	4.40 10^{-5}±2.2$10^{-6}$	87.65±4.38	1,78±8.90 10^{-2}	179,17±8.96
Bocou	156.06±0.01	4.00 10^{-5}±2.0.10^{-6}	80.59±4.03	1,94±9.70 10^{-2}	151,47±7.57
Yacé	156.85±0.01	4.50 10^{-5}±2.3 10^{-6}	89.85±4.49	1,75±8.75 10^{-2}	204,82±10.24
Manioc blanc	157.98±0.01	5.30.10^{-5}±2.6 10^{-6}	105.62±5.28	1,50±7.50 10^{-2}	149,34±7.47
Bonoua	156.20±0.01	4.70.10^{-5}±2.4$10^{-6}$	93.44±4.67	1,67±8.35 10^{-2}	131,73±6.59
Akaman	156.40±0.01	4.00.10^{-5}±2.0 10^{-6}	79.87±3.99	1,96±9.80 10^{-2}	191,02±9.55

Study of the drying kinetic of these cassava six varieties: The drying kinetics study of these cassava samples was doing by daily monitoring of their moisture evolution. This monitoring was conducted until all samples had daily moisture of less than 3% of their initial moisture. So, mass samples, between 156 and 158 ±0.01g, were exposed in the sun on a support covered with aluminum foil (to promote conductive drying in addition to that done by ambient air convection). The experiments were conducted during high insulation periods of March 2019, precisely from the 21st to the 29th of this month. With the exception of the first day, the moisture of these samples was evaluated at the end of each day. In fact, in order to follow the three step that take place during the thermal drying (the solid heating step, the constant drying rate step and the decrease rate drying step), ambient air temperatures, those of the aluminum support and samples were recorded hour by hour on the first day of drying, and at the end of the day for the other days of experiments. For other days of drying, the drying rate constant step was neglected because of the relatively high water loss observed during the first day of drying. The experiments were performed in triplicate.

Assessment of some characteristics of traditional solar drying in this study: The physical and chemical characterization of the traditional solar drying of these cassava varieties concerned with the determination of their mean heat transfer coefficient, mean vaporization enthalpy, mean critical moisture, mean overall diffusion resistance to water vapor and mean mass transfer coefficient.

The determination of their mean heat coefficient and mean vaporization enthalpy was done considering the constant drying rate step. Indeed, this drying step is generally considered adiabatic drying[20-22]. Under equilibrium conditions, the heat used to evaporate the water on the surface of the product is expressed according to Jacquet et al.[23] by:

$$\frac{dm}{dt} = \frac{h_c S_p}{L_V}\left(T_a - T_p\right) \quad (1)$$

With m, the mass of the product; hc, the heat transfer coefficient, S_P, the exchange surface of the product; Lv, the vaporization enthalpy; Ta and Tp, respectively the temperature of the air and the temperature product.

So, $\frac{h_c}{L_V}$ is a constant parameter. It is important for the drying process[15]. Considering that $\frac{h_c}{L_V} = \alpha$ (a constant) and, knowing that Van et al.[24] defines the coefficient of heat transfer by :

$$h_c = 393{,}856 - 0{,}0232T_P - 0{,}0497T_P^2 \quad (2)$$

It follows the expression of the enthalpy vaporization by:

$$L_V = \frac{h_c}{\alpha} = \frac{393{,}856 - 0{,}0232T_P - 0{,}0497T_P^2}{\alpha} \quad (3)$$

These formulae were used to obtain the mean heat transfer coefficient and mean vaporization enthalpy of these six cassava varieties used in this study.

The critical moisture of these cassava varieties was determined by plotting their drying rate versus their moisture. The critical moisture is obtained as the moisture from which the drying rate becomes constant.

The mean overall diffusion resistance to water vapor of these cassava varieties was obtained from considering drying decrease rate. According to Loncin[25], this step is characterized by:

$$\log\left(\frac{X - X_f}{C}\right) = -\frac{S_P}{mR_{ds}}t = at \quad (4)$$

With: C, the integration constant given by: $C = X_{in} - X_f$ (X_{in} the initial moisture and X_f the final moisture); S_p the exchange area of cassava, expressed by: $S_p = S_0$ for the constant drying rate step and, $S_p = 0.8S_0$ for the decrease drying rate step (S_0, initial exchange area of cassava)[26,27]; m, mass of the cassava sample at time t, R_{ds}, overall diffusion resistance to water vapor.

From the plot of the function given by the relation (4), the slope (a) of the linear adjustment line is easily deduced, followed by that of the mean overall diffusion resistance to water vapor of each cassava variety, using the following formulae:

$$R_{ds} = -\frac{S_P}{am} \quad (5)$$

The mean mass transfer coefficient of these cassava varieties was obtained from the mass transfer equation in the case of the thermal drying established by Jacquet et al.[23]. This equation is given as follow:

$$\frac{dm}{dt} = K_P S_P (P_S - P_V) \quad (6)$$

P_s the partial pressure of the water vapor at the temperature T_p of the product, expressed according to Koua et al.[15] and Touré and Kibangou-nkembo[26,27] by:

$$P_S = A_W . P_{vsat} \quad (7)$$

P_{vsat}, the partial pressure of the pure water vapor (in Pa) at the temperature $T_{P,}$ is given according to Dalzotto et al.[28] by:

$$\log P_{vsat} = 2{,}7877 + \frac{7{,}625 T_P}{241{,}6 + T_P} \quad (8)$$

and A_W, the cassava water activity, given by Touré and Kibangou-nkembo[26-27] as follow:

$$A_W = \exp\left[-0{,}5\left(\frac{1}{X} - \frac{1}{X_{in}}\right)^{0{,}27}\right] \quad (9)$$

P_V, the partial pressure of the water vapor at the temperature T_i of the air, given according to Nadeau and Puiggali[29] by:

$$P_V = \frac{101325 W}{W + 0.622} \quad (10)$$

W, the mean absolute air humidity derived a diagram of humid air.

Statistical techniques used: In addition to standard techniques such as mean (m) and standard deviation (s), the Normalized Principal Component Analysis (NPCA), the Student's Test (r') and the Ascending Hierarchical Classification (AHC) have been used.

NPCA was used to study correlations between some characteristics of these cassava varieties, in order to highlight common dimensions for classifying them, and to deduce their specific effects on certain groups formed from these cassava varieties. For its realization, it was used as characteristics of these cassava varieties: the initial mass, different exchange areas, the initial mean volume, the mean heat transfer coefficient, the density, the initial moisture, the critical moisture, the mean heat transfer coefficient, the drying rate during constant step, the mean vaporization enthalpy, the mean overall diffusion resistance to water vapor and the mean mass transfer coefficient. Correlations were considered significant at $p < 0.05$.

As for the Student's test, it was used to evaluate correlations two by two between parameters used for the realization of NPCA. This test was performed in a confidence interval of 0.5. The correlations considered significant were also correlated for $p < 0.05$ at N observations at ignored mean values.

AHC was used to highlight a typology of these cassava varieties. For its realization, it was used the same database that served to the NPCA.

The implementation of these different statistical techniques was done by Statistica software version 13.0.0[30] in this study.

Results and discussion

Drying kinetic: Final moisture of less than 3% of their initial moisture for all the six cassava varieties is obtained after seven consecutive drying days. All drying curves obtained in this study have a decreasing algorithmic appearance (Figure-1). In general, there is a relatively high daily decrease in the moisture of these cassava samples with the drying time increase; with the exception of Yacé which has a slowdown in its drying from 23 h. The order of the moisture of these cassava varieties at the initial time is practically the same as that at the end of experiments, except the inversion of Manioc blanc rank with that of Bonoua in the second order, as shown below:

at the beginning of experiments : Bonoua < Manioc blanc < Bocou < Yavo < Akaman < Yacé
at the end of experiments: Bonoua < Bocou < Manioc blanc < Yavo < Akaman < Yacé.

The monitoring of the drying rate of these cassava varieties shows that the variation of this parameter takes place in two steps: i. the first step, marked by a constant drying rate, is observed during the first four hours during the first day of drying; ii. the second phase, following the first step, characterized by a decrease drying rate as the drying time increase.

With exception of Akaman and Bocou, which have the lowest and the highest initial rate respectively, other cassava varieties have approximately the same initial rate. However, at the end of experiments, Yacé and Bonoua successively present the highest drying rate, while other varieties have substantially the same rate (Figure-2).

The aluminum support temperatures are very slightly higher than those of the ambient air throughout experiments. It the same case of samples temperatures, which are lower than those of the ambient air and the aluminum support. This difference in temperature is relatively important between 0 to 0.5h. It drops after 0.5h, particularly at 4h when Yavo and Bocou have the same temperature with the ambient air and the aluminum support (Table-2).

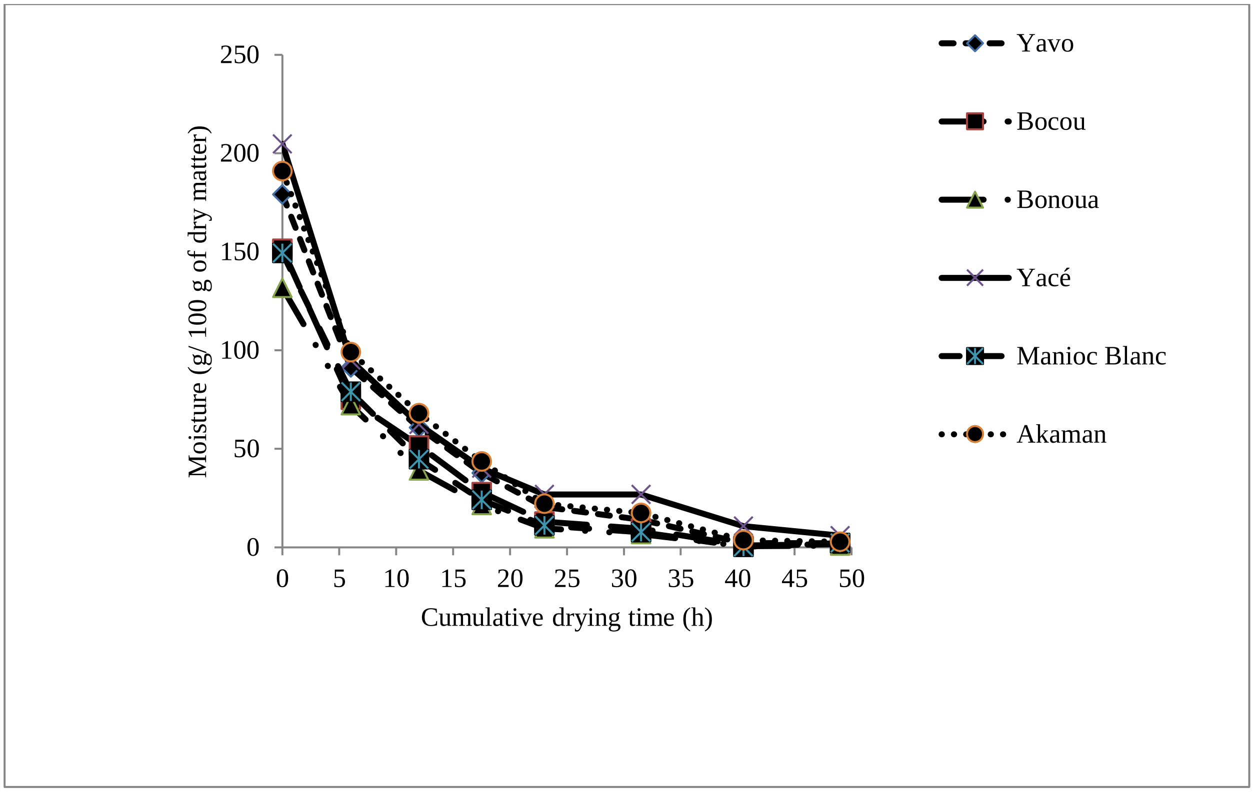

Figure-1: Hourly dynamics of the moisture of the six cassava varieties.

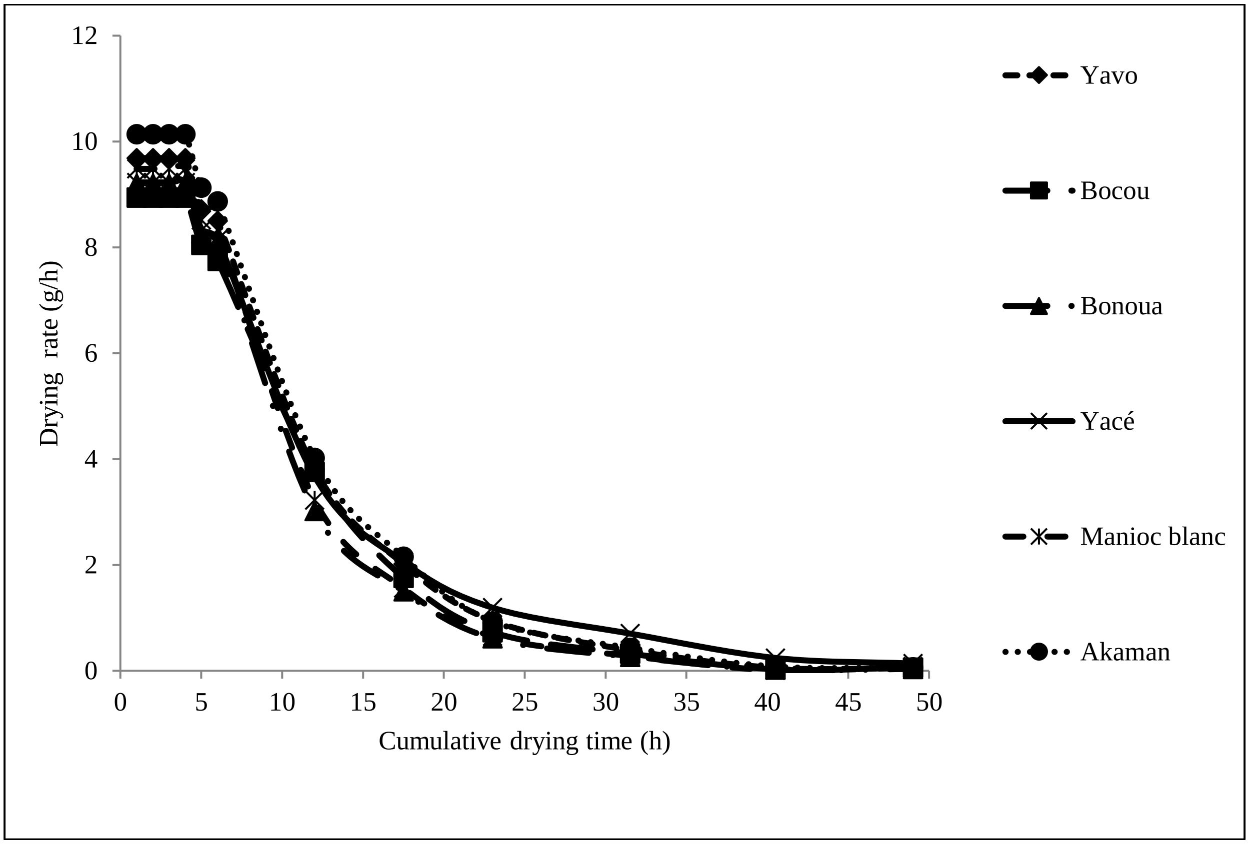

Figure-2: Evolution of the drying rate of the six cassava varieties.

Table-2: Hourly evolution of the ambient temperature (^{oC}), the aluminum support temperature (^{oC}) and samples temperatures (^{oC}).

Cumulative drying time (h)	Aluminium support	Ambient air	Yavo	Yacé	Manioc Blanc	Bonoua	Bocou	Akaman
0	33.4±0.1	33.2±0.1	25.9±0.1	24,6	25.1±0.1	24.9±0.1	26.4±0.1	25.3±0.1
0,5	37.0±0.1	34.0±0.1	31.4±0.1	30,5	30.1±0.1	29.4±0.1	30.4±0.1	30.1±0.1
1	34.7±0.1	35.6±0.1	32.2±0.1	31,5	30.7±0.1	30. ±0.16	30.9±0.1	30.7±0.1
1.5	36.4±0.1	36.4±0.1	34.2±0.1	32,8	32.1±0.1	31.6±0.1	32.9±0.1	33.2±0.1
2	36.7±0.1	37.4±0.1	35.1±0.1	34,1	32.5±0.1	33.2±0.1	34.2±0.1	33.8±0.1
2.5	39.5±0.1	37.3±0.1	35.8±0.1	33,7	33.4±0.1	33.7±0.1	35.0±0.1	33.4±0.1
3	37.6±0.1	37.5±0.1	36.2±0.1	34,9	35.2±0.1	34.7±0.1	35.5±0.1	34.9±0.1
4	36.9±0.1	36.0±0.1	36.0±0.1	34,1	34.8±0.1	33.7±0.1	36.0±0.1	34.3±0.1
5	32.5±0.1	32.4±0.1	31.6±0.1	30,3	30.1±0.1	30. 3±0.1	30.7±0.1	30.6±0.1
6	30.7±0.1	30.6±0.1	29.9±0.1	29,1	28.8±0.1	28.3 ±0.1	28.7±0.1	28.9±0.1
12	29.7±0.1	29.6±0.1	28.9±0.1	28,1	27.8±0.1	27. 3±0.1	27.7±0.1	27.9±0.1
17.5	30.7±0.1	30.6±0.1	29.9±0.1	29,1	28.8±0.1	28.3±0.1	28.7±0.1	28.9±0.1
23	27.7±0.1	27.6±0.1	26.9±0.1	26,1	25.8±0.1	25.3±0.1	25.7±0.1	25.9±0.1
31.5	29.7±0.1	29.6±0.1	28.9±0.1	28,1	27.8±0.1	27.3±0.1	27.7±0.1	27.9±0.1
40.5	29.7±0.1	29.6±0.1	28.9±0.1	28,1	27.8±0.1	27.3±0.1	27.7±0.1	27.9±0.1
49	29.7±0.1	29.6±0.1	28.9±0.1	28,1	27.8±0.1	27.3±0.1	27.7±0.1	27.9±0.1

Physical and chemical Characteristics of the traditional solar drying of these six cassava varieties: The different results obtained are shown in Table-3. Each cassava variety has a distinct h_c/L_v value, with ascending order established as follows:

Yavo < Manioc blanc < Bonoua < Yacé < Bocou < Akaman.

All these cassava varieties have a relatively high mean heat transfer coefficient, with values very close to each other. In this study, the increasing order of the mean heat transfer coefficient for these cassava varieties is:

Yavo < Bocou < Yacé < Akaman < Manioc blanc < Bonoua.

As for the mean evaporation enthalpy of these cassava varieties, it is also relatively important. Each cassava variety has a distinct vaporization enthalpy. In this study, the increasing order of the mean evaporation enthalpy for these varieties of cassava is:

Akaman < Bocou < Yacé < Bonoua < Manioc blanc < Yavo.

With ranking of the mean heat transfer coefficient and that of the mean evaporation enthalpy, it is observed that Bocou, Akaman and Yacé simultaneously exhibit relatively lows mean heat transfer coefficient and mean evaporation enthalpy values. In opposite, Manioc blanc and Bocou present highest values in these parameters. As for Yavo, it has both the highest mean evaporation enthalpy value and the lowest mean heat transfer coefficient value.

It is noted that all these cassava varieties have critical moisture greater than 1 g/g of dry matter, except Bonoua. Yacé has the critical moisture highest value and Bonoua its lowest value. The increasing order in this parameter for these cassava varieties is:

Bonoua < Bocou < Manioc blanc < Yavo < Akaman < Yacé.

This order is similar to the initial moisture of these cassava varieties, with the difference that Bocou rank is exchange with that of Manioc blanc.

The different mean overall diffusion resistances to water vapor of these cassava varieties illustrate the importance of this parameter for them. Akaman has the mean overall diffusion resistance to water vapor highest value, and Yacé the lowest value. The increasing order in the mean overall diffusion resistance to water vapor for these cassava varieties as follow:
Yacé < Bonoua < Bocou < Yavo < Manioc blanc < Akaman.

The mean mass transfer coefficients obtained are relatively important by referring to the type of the drying used in this study. Yacé has the highest mass transfer coefficient, and Manioc blanc the lowest. The increasing order in this parameter for these cassava varieties is as follows:

Manioc blanc < Bonoua < Akaman < Bocou < Yavo < Yacé.

h_c , the mean heat transfer coefficient; L_v, the mean vaporization enthalpy; CM, the critical moisture, Rds, the mean overall diffusion resistance to water vapor; Kp, the mean mass transfer coefficient.

Correlation and ascending hierarchical classification: The analysis in Figure-3 shows that NPCA expresses to 71.46% the information due to the 11 variables relating to the six individuals. The first axis, corresponding to the highest eigenvalue (4.60), represents 41.79% of the total variance. As for the second axis, associated with the second eigenvalue (3.26), it represents it at 29.67%.

The initial mass, the exchange area, the initial mean volume and the mean heat transfer coefficient are negatively correlated with the factor 1; while the density, the initial moisture and the critical moisture are positively correlated to this axis. The drying rate during constant step, the mean heat transfer coefficient, the mean vaporization enthalpy, the mean overall diffusion resistance to water vapor and the mean mass transfer coefficient are all negatively correlated to the factor 2 (Table-4).

For individuals, Yavo is positively correlated with F1. Manioc blanc (M blanc) and Bonoua are negatively correlated with this factor. Bocou is positively correlated with F2 and, Akaman negatively correlated with this second factor (Table-5).

With regard to the Student's test, results obtained show a good correlation of the exchange area with the mean initial volume (r' = 1.00) and the density (r' = -0.99), the mean initial volume with the density (r'=-0.99), the initial moisture with the critical moisture (r'= 0.99), the mean heat transfer coefficient with the mean evaporation enthalpy (r'=0.84) and the mean mass transfer coefficient (r'= 0.84), the mean mass transfer coefficient with the mean evaporation enthalpy (r'=1.00) and the drying rate during constant step with the mean overall resistance to vapor diffusion (r'= 0.88).

Regarding the use of AHC in this study, it revealed the existence of three distinct classes in order of importance and composed of: Akaman (1^{st} class), Bonoua, Yace and Bocou (2^{nd} class) and, of Manioc blanc and Yavo (3^{rd} class) (Figure-3).

Table-3: Physical and chemical characteristics of the six cassava varieties studied.

Cassava varieties	h_c/L_v (Kg/sm^2°C)	h_c (W.m^2.°C^{-1})	L_v (KWh.kg^{-1})	CM (g/g of dry matter)	Rds (m^{2}s/Kg)	Kp (kg/sm^{2}bar)
Yavo	$1.94\ 10^{-4}$ $\pm 9.70\ 10^{-6}$	334.20 ±16.71	$1.72\ 10^{7}$ $\pm 8.60\ 10^{5}$	1.21 ±0.06	4660.55 ±233.03	$1.47\ 10^{-4}$ $\pm 7.37\ 10^{-6}$
Bocou	$3.82\ 10^{-4}$ $\pm 1.91\ 10^{-5}$	337.11 ±16.86	$8.82.10^{6}$ $\pm 4.41\ 10^{4}$	1.01 ±0.05	4371.65 ±218.58	$1.46\ 10^{-4}$ $\pm 7.30\ 10^{-6}$
Bonoua	$2.62\ 10^{-4}$ $\pm 1.31\ 10^{-6}$	340.88 ±17.04	$1.30.10^{7}$ $\pm 6.50\ 10^{4}$	0.92 ±0.05	4 106.17 ±205.31	$1.19\ 10^{-4}$ $\pm 5.93\ 10^{-6}$
Yacé	$3.52\ 10^{-4}$ $\pm 1.76\ 10^{-6}$	338.68 ±16.93	$9.62.10^{6}$ $\pm 4.81\ 10^{5}$	1.32 ±0.07	4185.88 ±209.29	$1.50\ 10^{-4}$ $\pm 7.48\ 10^{-6}$
Manioc Blanc	$2.56\ 10^{-4}$ $\pm 1.28\ 10^{-6}$	340.00 ±17.00	$1.33.10^{7}$ $\pm 6.65\ 10^{4}$	1.03 ±0.05	4774.43 ±238.72	$1.09\ 10^{-4}$ $\pm 5.47\ 10^{-6}$
Akaman	$4.14\ 10^{-4}$ $\pm 2.07\ 10^{-6}$	339.25 ±16.96	$8.19.10^{6}$ $\pm 4.1\ 10^{4}$	1.31 ±0.07	5408.96 ±270.45	$1.24\ 10^{-4}$ $\pm 6.22\ 10^{-6}$

Table-4: Factorial coordinates of variables based on correlations with the first two factors.

Variables	Factor 1	Factor 2
Initial mass	-0.727	-0.255
Exchange area	-0.921	0.052
Initial mean volume	-0.923	0.066
Density	0.910	-0.122
Initial moisture	0.612	-0.286
Drying rate during constant step	0.293	-0.777
Mean heat transfer coefficient	-0.666	-0.520560
mean vaporization enthalpy	-0.306	-0.864
Critical moisture	0.615	-0.388
Mean overall diffusion resistance to water vapor	0.265	-0.758
Mean mass transfer coefficient	-0.306	-0.864

Significant correlations to $p < 0.05$ in bold.

Table-5: Factorial coordinates of individuals based on correlations with the first two factors.

Individuals	Factor 1	Factor 2
Yavo	1.706	1.390
Bocou	1.290	1.837
Yacé	0.341	0.367
M blanc	-3.343	-0.461
Bonoua	-1.883	0.130
Akaman	1.889	-3.263

Significant correlations to $p < 0.05$ in bold.

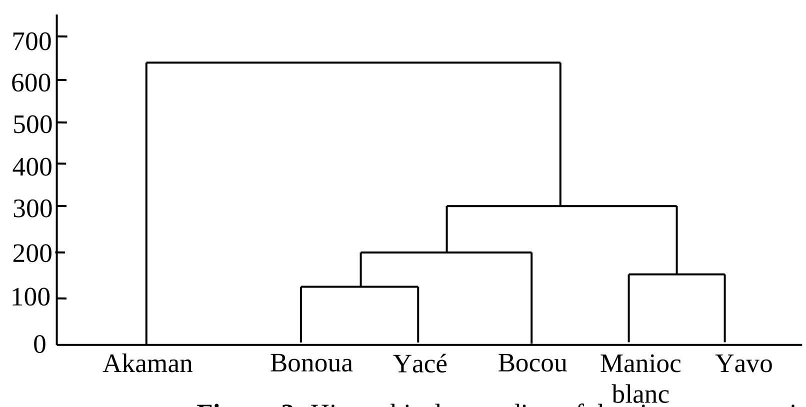

Figure-3: Hierarchical ascending of the six cassava varieties.

Discussion: The decreasing algorithmic appearance of different drying curves obtained in this study are similar to those obtained by Koua et al.[15], Tieu et al.[16], Toure and Kibangou-Nkembo[26-27], and this in studies of cassava drying in a solar oven. So, it can be generalized that the solar drying curve of cassava is a descending algorithm function.

Between 0 and 0.5h, the high difference observed between samples temperatures of these cassava varieties and those of the ambient air would correspond to the warm-up period of the different cassava samples, as mentioned by CEFIAT[20], Karoui[21] and Remache and Belhamri[31]. As in the classic case of thermal drying[20-22], samples temperatures during the constant rate drying step (between 0.5 to 4h) is very close to those of the ambient air. Unlike the solar oven[15,16,26,27] and some thermal drying systems[20,21], samples temperature always remains slightly lower than those of the ambient air during the decrease rate drying step. This phenomenon is explained by the action of the wind because of its relatively high speed and, at the air humidity in the case of the traditional solar drying[32]. Also, it is necessary to mention the spatial distribution of samples in these experiments, which would contribute to this fact. The action of the wind and the relative air humidity would also explain the low difference observed between ambient air temperatures and those of the metallic support used in this study.

In direct solar drying, materials to be dried are simultaneously subjected to conductive drying and convective drying. The conduction drying is carried out by the ambient hot air. As for conductive drying, it is carried out by induction of the support heated by the ambient hot air, support on which materials to be dried are exposed. These two phenomena lead in this type of drying to the evaporation of the liquid contained in these materials, and therefore to their drying[33,34]. In the particular case of cassava, there is also observed a loss of "free water" by the cassava flesh in addition to these two phenomena mentioned above. This loss of water in its liquid form would be due to these two thermal phenomena and/or biochemical activities. Thus, these three phenomena are observed simultaneously in the particular case of a cassava drying. The importance of these phenomena during the different steps of direct solar drying would depend on the nature of cassava. This fact would explain contradictions observed in the evolution of the initial moisture of these cassava varieties with their drying rates. It would be explained also the inversion of Bocou rank with that of Manioc blanc in the initial order of their moisture with that obtained at the end of experiments. These phenomena lead to structural atrophy of cassava samples. This results in a strong correlation between the exchange area with the initial mean volume and the density of these cassava varieties over the study period. The slowing down of Yacé's drying rate from 23h of drying is due to its "bitter" manioc character. That is due to the high presence of cyanogenic glucosides in this cassava, which are removed during drying[17,35-38].

The relative high critical moisture of these cassava varieties obtained in this study would explain, in general, the difficult conditioning of cassava flesh in ambient air and under some conditions over a period of time (usually after 2 to 3 days). Beyond this value, the flesh structure of cassava loses its rigidity (consistency) and becomes increasingly soft with increasing exposure time. It follows the loss of its flavor and its decomposition. The loss of cassava flavor is related to the production of hydrocyanic acid[17,35,36]. The loss of cassava flesh rigidity would occur in varieties with high initial moisture, based on the strong correlation between the initial moisture and the critical moisture in this study. Manioc blanc would have a relatively high water loss during the constant rate drying step. This would justify the inversion of its rank with that of Bocou in the order of the critical moisture compared to that of the initial moisture of these cassava varieties.

The different $\frac{h_c}{L_v}$ values of these cassava varieties are slightly higher than the value obtained by Koua et al.[15] (1,448.10^{-4} Kg/sm^2°C) when drying cassava in a direct solar oven. As a result, it can be generalized that all cassava varieties have $\frac{h_c}{L_v}$ value of the order of 10^{-4} Kg/sm^2°C in direct solar drying. The mean vaporization enthalpy values and those of the mean heat transfer coefficient of these cassava varieties are relatively important with regard to the type of the drying used in this study. The importance of the mean heat transfer coefficient in this study is thought to be due to texture and consistency of cassava flesh similar to that of wood[39,40]. The relatively low difference observed between mean heat transfer coefficient values of these six cassava varieties illustrates the similarity of their texture. Of these six cassava varieties, Bonoua's flesh appears to be the most consistent and that of Yavo the least. The high mean vaporization enthalpy values obtained in this study show a relatively high presence of "free water" in cassava in general[20]. Of the six cassava varieties studied, Yavo would contain the most "free water" and Akaman the least.

These cassava varieties have relatively high mean overall diffusion resistances to water vapor, depending on the type of drying used and temperatures involved. As in other types of thermal drying, the mean overall diffusion resistance to water vapor of these varieties grow with the drop in their moisture and therefore with the decrease of the drying rate[15,20,21]. This justifies the low mean overall diffusion resistance to water vapor for Yacé, drying slowly and, the highest value for Akaman, drying the fastest during the decrease rate drying step. The impact of drying rate on the mean overall diffusion resistance to water vapor is shown in this study by the strong correlation observed between the mean overall diffusion resistance to water vapor and the drying rate at the beginning of the decrease rate drying step.

As in the case of the mean overall diffusion resistance to water vapor, the mean mass transfer coefficient of these cassava varieties are important if we consider the type of the drying used in this study. The strong presence of cyanogenic glucosides in Yacé, responsible for slowing its drying during the decreasing phase, would also be responsible for its mean mass transfer coefficient value. For Manioc blanc, the low presence of cyanogenic compounds would justify its mean mass transfer coefficient value, the lowest in this study. The impact of the solar power source in this study is evidenced by the strong correlation of the mean mass transfer coefficient with the enthalpy vaporization and the mean overall diffusion resistance to water vapor.

Further study by NPCA showed the simultaneous influence of the density, the initial moisture, the initial mean volume and the exchange area of Yavo, Manioc blanc and Bonoua on their critical moisture, moisture and mean heat transfer coefficient. This study also revealed the influence of drying rate in constant step of Bocou and Akaman on their mean heat transfer coefficient, mean evaporation enthalpy, mean overall diffusion resistance to water vapor and mass transfer coefficient. Indeed, the typology established by NPCA has shown that the relative high critical moisture of Yavo and Bonoua would be favored by their density and initial moisture; but this parameter would be partially inhibited by their exchange area, mean initial volume and initial mass. That is the opposite for their mean heat transfer coefficient. For Manioc blanc, the opposite is observed. As for Bocou, its mean vaporization enthalpy, mean overall diffusion resistance to water vapor, mean heat transfer coefficient and mean mass transfer coefficient would be favored by the drying rate during the decrease step. That is opposite for Akaman.

The three classes obtained by AHC showed the particularity of Akaman compared to other cassava varieties studies. The class formed by Yacé, Bonoua and Bocou illustrates that these three varieties have common genes; in other words, they would come from the same strain by genetic improvement. This is also the case of the class formed by Manioc blanc and Yavo.

Conclusion

This study is a contribution to the knowledge of traditional drying of plants in general, and cassava in particular. The different results obtained have made it possible to set up the traditional solar drying of cassava similar to that achieved by innovative solar drying techniques, unlike the drying time which is important on the one hand, and the importance of physical and chemical characteristics for this type of drying in other hand. Thus, results obtained can serve as a basis for further studies aimed at deepening knowledge on the traditional solar drying of plants in general, and agricultural products in particular.

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