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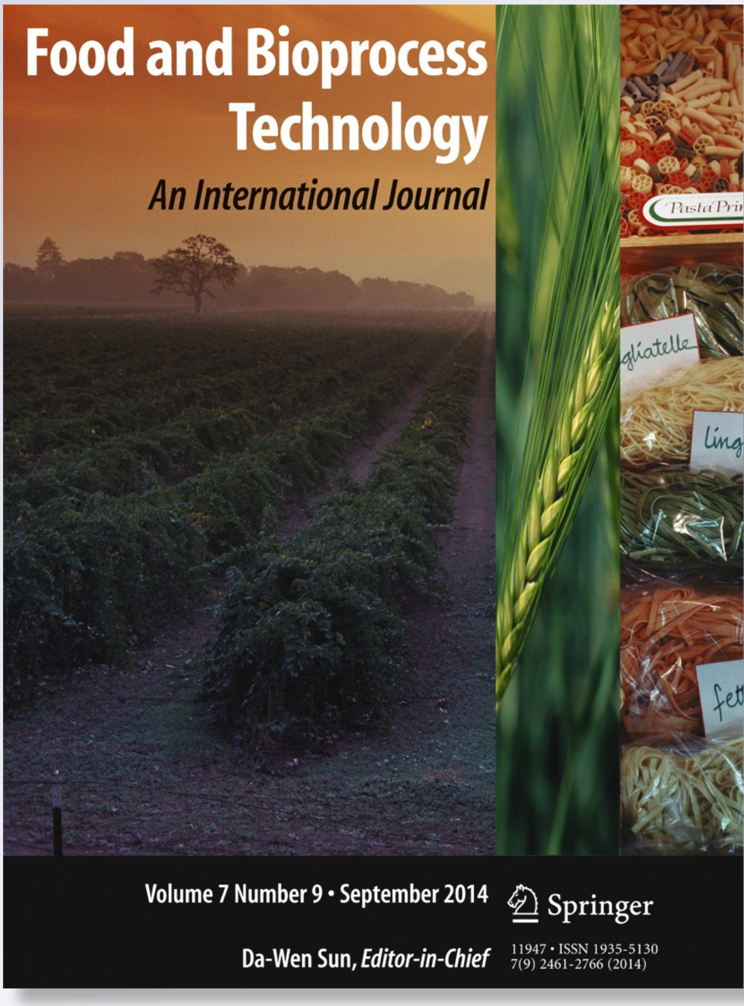

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COMMUNICATION

Combined Smoking and Drying Kinetics of Retted Cassava Pulp and Effects on the Physicochemical and Pasting Properties of the Extracted Starch

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Abstract Cooked paste of smoked-dried flour of retted cassava is the staple food of million people in West and Central Africa. The present study investigates the dynamics of combined smoking and drying on some physicochemical and functional properties of the flour and its derived starch. Fresh cassava tubers (variety 4115) were trimmed, retted, wrung, crushed, put into balls and then dried using three processes: traditional combined smoking and drying, electrical combined smoking and drying, and oven-drying. The drying processes did not significantly modify ($p>0.05$) the proximate composition of samples neither their drying rates ($0.19\ h^{-1}<k<0.22\ h^{-1}$). A positive and significant correlation was shown between the drying constant k and the smoking constant k_s ($p<0.05$). The colour of the oven-dried flour sample was clearer with the highest whiteness index (86.11 ± 0.76) than the flour from traditional and electrical combined smoking and drying processes (65.41 ± 4.35 and 68.18 ± 3.98, respectively). The peak viscosity and breakdown values of retted starch paste were significantly higher ($p<0.05$) than that of the flour from which it originated. Meanwhile, the starch cold paste exhibited lower setback values and thus a lesser tendency to retrogradation when compared to retted flour gel. All this suggests that despite the relative instability of temperature in the traditional attic, it preserves, in comparable extent, the functional and nutritional values of cassava derivatives as electrical drying processes. Considering the functional use of the retted cassava for fufu preparation, smoked-dried starch is more suitable for cooking than oven-dried starch. In addition, the electrical combined smoking and drying process appeared as the best drying method, since the derived product has low tendency to retrogradation.

Keywords *Manihot esculenta* · Drying rate · Smoking rate · Pasting properties · Fufu · Starch

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Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most consumed tubers in Asia, Latin America and Africa (Nweke 2004). In Cameroon, the tuber is the most agricultural commodity produced in terms of annual tonnage (FAO 2010). For poor farmers, cassava is vital for both food security and as a source of income. Meanwhile, the post-harvest use of fresh tuber encounters two major constraints: perishability due to its water load and toxicity related to the presence of cyanogenic compounds in the root (Djouldé et al. 2007). To overcome these limitations, the fresh root is processed into more stable and non-toxic products (chips, gari, sticks and flour) through retting. Retted cassava flour, locally called "kum kum" or "fufu flour" in Cameroon (Numfor and Ay 1987), is one of the main products of secondary processing of cassava after retting.

The production of cassava flour goes usually through sun drying of the retted cassava paste. Though this energy source is almost permanent in savannah regions, rainfall and humidity reduce this opportunity in forest regions. Then, in the latter regions, the retted cassava paste is currently dried using combined smoking and drying process. In this respect, retted cassava paste is moulded in the form of balls which are displayed on an attic above fire. This operation is usually conducted in kitchen. The quality of fufu, a cooked paste, prepared from sun-dried or combined smoked and dried cassava flour, is fundamentally different (Shittu and Adedokun 2010). Indeed, smoking ameliorates flavour and colour of cassava products, contrary to unique sun drying (Osundahunsi and Oluwatooyin 2005). However, consumption of smoked-dried fufu remains relatively localized in some ethnic areas of the forest zone. This may explain why the scientific and technological systems have shown little interest for smoked-dried cassava, compared to solar-dried one. Indeed, the current technological value of these flours in the traditional processing system of fufu remains unclear.

The scientific interest in combined drying and smoking of cassava is recent. Osundahunsi and Oluwatooyin (2005) examined the effect of drying methods on some physico-chemical properties of the smoked-dried balls. Stability and downside risks by microorganisms of smoked-dried cassava flour during storage were also evaluated (Shittu et al. 2009; Famurewa et al. 2012). However, the existing research works have not addressed the dynamic of drying associated with smoking or the effect of that process on the functional properties of starch (main cassava component) extracted from the smoked flour.

The present paper aims at studying, in the combined drying and smoking process, the behaviour of the cassava paste and the quality of the flour.

Materials and Methods

Source and Preparation of Cassava Tubers

Cassava tubers, improved variety 4115, were obtained from research experimental station (IRAD, Ngaoundere, Cameroon). After harvest, tubers were directly processed within a maximum of 2 days. The tubers were peeled using a knife with a stainless steel blade. The pulp was washed with tap water and then cut into small parallelepiped pieces (6 cm long, 4 cm wide and 2 cm thick) and retted by immersion in water (3 kg of cassava pulp for 2 L of water) at 24±2 °C, using a plastic basin.

Processing of Retted Cassava Tubers into Moulded Balls

The fermented cassava pieces were removed from the soaking water after 72 h and washed with tap water, then dewatered by introduction in woven nylon bag, overloaded with heavy weights for 12 h, in order to reduce water content by 45 % (Shittu and Adedokun 2010). Fibres were manually removed from the partially dewatered product, and the resulting pulp was mashed using an electric crusher of artisanal manufacture and moulded in spherical balls of about 300 g each. In order to standardize the dimensions and texture of moulded paste, a stainless steel device consisting in two hemispheres of 7-cm diameter and a compression chamber (Fig. 1) was used. The device was adjusted with the aid of a crank linked to a vertical screw. The lower cup, surrounded by the compression chamber, was fixed on a horizontal metallic platform. The upper cup, guided by the screw, was brought down vertically and fitted upon the lower cup, in which the retted mash has been previously introduced on about 14–15-cm height. Once a single pressure has been exerted, the upper cup was removed and the moulded ball was extracted.

Drying

The drying of moulded cassava balls was undergone in three ways:

- Combined drying and smoking by displaying moulded cassava balls on a wooden rack placed 90 cm above fire (traditional method). The temperature around the balls varied between 62 and 75 °C, and the ambient relative humidity (RH), measured using a hygrometer (Hanna Instruments, Romania), was about 68 %.
- Combined drying and smoking in electric smoker (Matindex, France); $T°=62\pm2$ °C, RH=68 %, air velocity=0.8 m/s
- Electric oven-drying (Memmert brand); $T°=62\pm2$ °C, RH=68 %, air velocity=0.8 m/s

Study of the Drying Kinetics

During the drying process, the balls were collected at predefined time intervals (0, 1, 2, 3, 4, 5, 6, 8, 10, 12, 14, 16, 18 and 20 h) and weighed using an electronic balance (Sartorius, precision 0.01 g), and water content was determined (AFNOR 1982). For each drying batch, approximately 30 balls of 300 g each were displayed on the drying grid and two balls were withdrawn at regular time intervals.

Two approaches were considered during this study: a global approach, consisting in following the drying kinetics in the whole ball, and a thin-layer approach. In the latter, the balls collected at preset time intervals were cut in thin slices of 1-cm thickness, using a handcrafted slicer with six stainless steel blades spaced 1 cm from each other. Seven slices was obtained from each cassava ball and weighed in the same conditions as the whole ball for drying kinetics.

The data collected from the two approaches were used to build the drying curves and to calculate the drying parameters. These parameters, consisting in the equilibrium moisture (H_e) and the drying constant (k), were determined from the simplified equation (1) of Henderson and Perry (1976) and Perry et al. (1984) expressing the removable moisture ratio (H_r) of samples during drying. The equation assumes the Fickian diffusion model and the analytical solution proposed by Crank (1975), considering that the evaporation surface of the ball or of the slices is infinitely larger than its

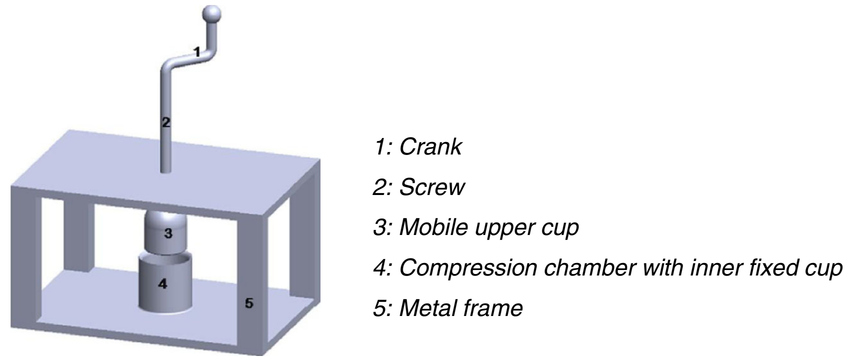


Fig. 1 Moulding device

thickness and that water repartition is uniform in the ball.

$$Hr = Ht{-}HeH0{-}He = e{-}kt \quad (1)$$

where

- H_r Removable moisture ratio (g H_2O g^{-1} DW)
- H_t Time dependent moisture content of the sample during drying (t) (g H_2O g^{-1} DW)
- H_0 Initial water content (g H_2O g^{-1} DW)
- H_e Equilibrium moisture content (g H_2O g^{-1} DW)
- t Drying time (h)
- k Drying constant (h^{-1}), obtained from the plot of lnH_r versus t

Considering that at equilibrium state, the drying speed is zero, that is dH_t/d_t=0 and H_t=H_e; therefore, from plots of near equilibrium final values of dH/d_t versus H_t, and through regression analyses, H_e values were determined as the point where the graph cuts the H_t axis. The values obtained were included in Eq. 1 for the determination of drying constant (k).

Production of Fufu Flour and Starch

At the end of the drying and/or smoking processes, the dried balls were milled using a traditional mortar and sieved to remove fibre, using a 300-μm mesh sieve. The smoked-dried balls were milled after removing the brown crust recovering the surface of the ball, by scraping, using a stainless steel knife, and sieved in the same conditions as above. Starch was then extracted from flours according to the modified method of Sathe et al. (1982). All samples (flour and starch) were packed in waterproof plastic bags and kept in dry environment, at room temperature, until physicochemical analyses. Some pictures of wetted and dry balls and flour are shown on Fig. 2.

Physicochemical Analyses

Chemical analyses were undergone on cassava roots, flours and starch for protein content (AFNOR 1982), total ash, total fat, crude fibre (AOAC 1984) and cyanide level (Makkar et al. 2007). The colour of the flour and starch was measured using a Chromameter (Lovibond RT 100, South Africa), and the whiteness index (WI) was deduced using the formula of Saricoban and Tahsin Yilmaz (2010) (Eq. 2):

$$WI = 100\text{–}100{-}L{*}2 + a{*}2 + b{*}2 \quad (2)$$

Pasting Properties

Pasting properties of samples were determined according to the method described by Crosbie and Ross (2009) using Rapid Visco Analyser (RVA) (Perten Instruments, Tec Master Model, Australia). Water dispersions of starch (7 % in distilled water) and flour (10 % in distilled water) were used for this purpose. Viscosity was recorded using the following temperature profile: holding at 50 °C for 1 min, heating from 50 to 90 at 6 °C min^{-1}, holding at a 90 °C plateau for 5 min, and then cooling down to 50 °C at 6 °C min^{-1} with continuous stirring at 160 rpm. Six parameters were measured on the viscoamylogram: pasting temperature (PT) and pasting time (Pt), peak viscosity (PV) and

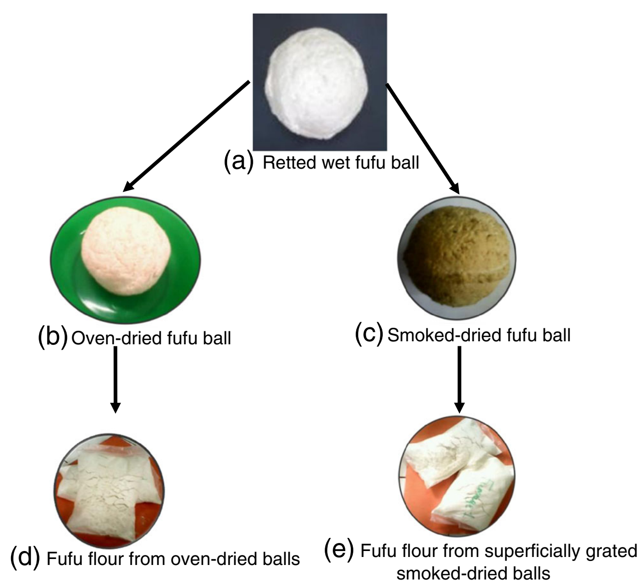


Fig. 2 Pictures of processed balls and flour

peak viscosity time (PVt), hot paste viscosity (lowest hot paste viscosity HPV) and cool paste viscosity at 50 °C (CPV). Four additional parameters were then calculated: cooking ability (CA), estimated as PVt-Pt; breakdown (BD), estimated as PV-HPV; setback (SB), estimated as CPV-PV; and consistency (CS), estimated as CPV-HPV.

Three replicates were carried out for each analysis, and means were obtained from replicates. These means were compared by analysis of variance (ANOVA), and where significant differences existed, means were classified using Duncan's multiple range test. Pearson correlation was carried out using the Statgraphics plus 5.0 statistical packages, while graphical representations were plotted using the SigmaPlot 11.0 graphics package (Chicago, IL, USA).

Results and Discussion

Smoking and Drying Kinetics of Retted Cassava

Figure 3 shows the drying rate of balls as a function of moisture content in the three drying methods (traditional combined smoking and drying, electrical combined smoking and drying and oven-drying). The drying rate decreases rapidly with the decreasing of the moisture content from an initial value of 0.82 g H_2O g^{-1} to approximately 0.4 g H_2O g^{-1}. During this period, the traditionally smoked-dried balls showed the highest initial rate corresponding to the warming phase, while electrical smoking and oven-drying showed comparable profile all along the process. These profiles agree with that of Akeredolu et al. (2003). The highest initial drying rate in the traditional smoked-drying process, almost two times higher than the drying rate in the two other processes, may be the result of difference in air temperature, pressure, velocity and humidity in traditional practice. In fact, temperature around the ball, in the traditional process, varied between 62 and 75 °C, while in the two other processes, it was fixed at 62 °C. In addition, the direction of movement of air fluctuated continuously during the drying process in the traditional method, contrary to the electrical methods. These variations in the traditional process may affect the initial drying rate as stated by VanArsdel (1973). Despite the above difference in initial drying profile from traditional and electric processes, the resulting drying constants (k and H_e) are comparable for all drying methods (Table 1), which suggests that in the conditions of the present study ($T°\approx62$ °C, RH≈68 %), the drying processes used do not influence the overall drying profile of retted cassava.

Drying parameters (H_e and k) of cassava slices (Table 2) indicate that whatever the drying process, k values decreased from the outer to the inner slice (0.51–0.17 h^{-1}), while H_e values were almost stable for all slices. The variation of k values indicates that the outer layers dry faster than the inner one, which is normal, since the water elimination at the surface creates a concentration gradient allowing water diffusion through the product (Karel and Lund 2003). The phenomenon is different from one drying method to another. Slices from traditional method display relatively lower H_e values and higher k values than slices from modern processes. In addition, drying values are comparable in both modern processes. It appears therefore for some interest to find whether this drying rate difference of slices as a function of drying methods has an effect on physicochemical properties of slices.

Influence of Smoke on Flour Colour

Despite they smoke and dry their fufu balls, consumers need whitish fufu to eat, not brownish one. So, smoked-dried fufu balls are always scratched superficially in order to remove the brownish coat before milling and cooking of fufu. The

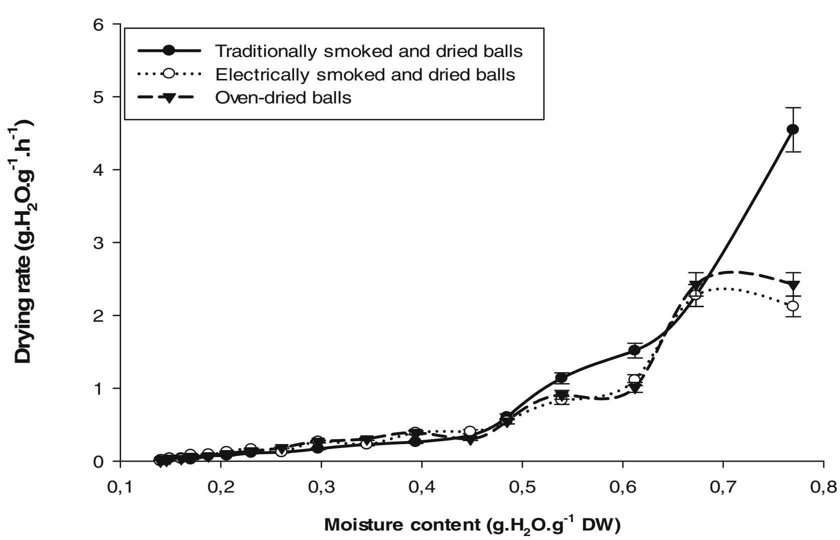


Fig. 3 Drying kinetics of retted cassava balls

Table 1 Equilibrium moisture content (H_e) and drying constant (k) of whole cassava balls

Drying method	H_e (g H_2O g^{-1} DW)	k (h^{-1})	R^2
Traditional combined smoking and drying	0.12^a	0.22^a	0.99
Electrical combined smoking and drying	0.11^a	0.20^a	0.99
Oven-drying	0.12^a	0.19^a	0.98

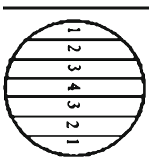
Values in the same column with the same letter are not significantly different ($p \leq 0.05$)

WI of the flour, indicating the extent of discoloration during the processes involved, showed that smoking (traditional or electric) reduces the whiteness of the product (Table 3). The reduced whiteness of flour results from the porosity of fufu ball, which allows phenol components and soot (aldehydes, monoaromatics, saturated and unsaturated hydrocarbons, polycyclic aromatic hydrocarbons and alkyl benzenes) impregnating the surface to diffuse in the inner part of the ball. The whiteness was improved on starch extracts, due to washing steps which allowed leaching of smoke components during the starch extraction process. However, the improvement was higher on starch from combined electric smoking and drying than on the one from traditional process. The difference in the smoke purity and quality between the two methods may explain the observed difference in starch whiteness. In traditional process, the balls are exposed directly in contact with smoking fire, with possibility of smoke to carry fine particles which come into contact with the product. While in electrical process, smoke is carried from a burning unit to a drying chamber, through filters, and may be considered purer than the one in traditional process, though the same wood variety is used in both methods. Thus, the risk of contamination and formation of organic complexes is lower in electric smoking process than in traditional one, which justifies the low purity of starch from traditional smoking process. Though WI values of starch were not different between oven-drying and electrical combined smoking and drying, the starch from the latter process looked more yellowish. This difference was confirmed by the b* (yellow to blue) colour parameter, confirming the presence of residual exogenous smoke compound on the smoked starch, despite the purity of the starch extraction process.

Analysis of WI as a function of smoking time (Fig. 4) gives an idea of the diffusion kinetics of smoke through cassava ball, as represented by the decrease of cassava flour and starch whiteness. Whatever the smoking process or the cassava ball slices, smoking kinetics have comparable trends, with outer part of cassava ball (slice 1) being more impregnated by smoke than inner parts (slices 2, 3 and 4). The smoking impregnates cassava ball at low speed during the first 5 h of smoking, followed by acceleration. This suggests that the impregnation of the ball by the smoke is more intense towards the end of the drying process. By plotting lnWI = f(t), following the logic of the equation of Henderson and Perry (1976), a smoking constant, k_s, is defined as the slope of the curve (k_s= 0.06±0.01 and 0.07±0.01, respectively, for electrical smoking and traditional smoking). This smoking constant (k_s) is positively and significantly correlated ($p<0.05$) with drying constant (k), both for traditional (r=0.954) and electrical (r= 0.985) combined smoking and drying processes (Fig. 5). This means that when the water removal is high, the smoke is more allowed to adhere easily on the food matrix. This may be explained by the fact that some smoke components are hydrophobic and could irreversibly bind with starch granules. Such components could have been acting as surfactant by reacting within swelling granules or by reducing the rate of water absorption (Longley and Miller 1971; Massaux et al. 2006).

Although smoke darkens slightly fufu colour, the smoked flour is well appreciated by million consumers in West and Central Africa in terms of sensory enhancement. Some

Table 2 Drying parameters (H_e and k) for retted cassava slices



	Traditional combined smoking and drying		Electrical combined smoking and drying		Oven-drying	
	H_e (g H_2O g^{-1} DW)	k (h^{-1})	H_e (g H_2O g^{-1} DW)	k (h^{-1})	H_e (g H_2O g^{-1} DW)	k (h^{-1})
Slice 1	0.16 ± 0.02^a	0.41 ± 0.03^A	0.15 ± 0.02^a	0.31 ± 0.01^E	0.15 ± 0.01^a	0.31 ± 0.01^E
Slice 2	0.12 ± 0.01^b	0.34 ± 0.01^B	0.14 ± 0.01^a	0.29 ± 0.0^F	0.14 ± 0.02^a	0.29 ± 0.01^F
Slice 3	0.12 ± 0.01^b	0.21 ± 0.0^C	0.15 ± 0.01^a	0.24 ± 0.02^G	0.15 ± 0.01^a	0.24 ± 0.02^G
Slice 4	0.12 ± 0.01^b	0.19 ± 0.01^D	0.16 ± 0.02^a	0.17 ± 0.01^D	0.15 ± 0.01^a	0.17 ± 0.03^D

Values in the same column or in the same line without the same lowercase letter(s) are significantly different ($p \leq 0.05$)

Values in the same column or in the same line without the same uppercase letter(s) are significantly different ($p \leq 0.05$)

Table 3 Colour parameters and whiteness index (WI) of retted cassava flour and starch from three different drying methods

	Drying method	L*	a*	b*	WI
Flour	Traditional combined smoking and drying	65.99±4.35[a]	0.7±0.06[a]	6.24±0.77[a]	65.41±4.35[a]
	Electrical combined smoking and drying	68.72±3.98[a]	0.54±0.06[b]	5.84±0.61[a]	68.18±3.98[a]
	Oven-drying	88.57±0.76[b]	0.11±0.04[c]	7.89±0.41[b]	86.11±0.76[b]
Starch	Traditional combined smoking and drying	86.70±1.69[b]	0.37±0.05[d]	6.48±0.23[a]	85.20±1.69[c]
	Electrical combined smoking and drying	90.75±0.33[c]	0.01±0.02[e]	5.84±0.20[c]	89.37±0.69[d]
	Oven-drying	91.12±0.69[c]	0.06±0.06[e]	4.00±0.09[d]	89.24±0.33[d]

Values in the same column without the same lowercase letter(s) are significantly different ($p \leq 0.05$)

studies reported that smoked fufu paste is rated higher than solar or mechanical dried fufu samples in terms of aroma, taste, texture, appearance and overall acceptability (Osundahunsi and Oluwatooyin 2005; Shittu and Adedokun 2010).

Chemical Composition of Retted Cassava Flour and Starch

The drying process did not significantly modify the chemical composition of the studied samples (Table 4). Meanwhile, it should be noted a slight increase of protein and lipid contents on retting and drying. Akindahunsi et al. (1999) and Oyetayo (2006) attributed this increase to biological activity of microorganisms, fungi in particular, involved in the fermentation process during retting. In addition, the comparable cyanide content in all dried samples seems to indicate that the detoxification effect of fermentation during retting is not significantly improved by drying, whatever the drying method.

The extraction yield of starch (≈96 %) and its relative purity in terms of fat and cyanide contents, indicate acceptable conditions of extraction. The analytical values obtained are consistent with those found by Vilpoux and Perdrix (1995) and Numfor and Walter (1996) in comparable conditions.

Pasting Properties of Retted Cassava Flour and Starch

Pasting properties of retted cassava starch and flour are shown in Table 5. These properties give an insight of “fufu” characteristics, the local paste obtained from the cooking of retted cassava flour, and which constitutes the main consumption form of cassava flour. They are also important indicators of starch behaviour during hydrothermal processing.

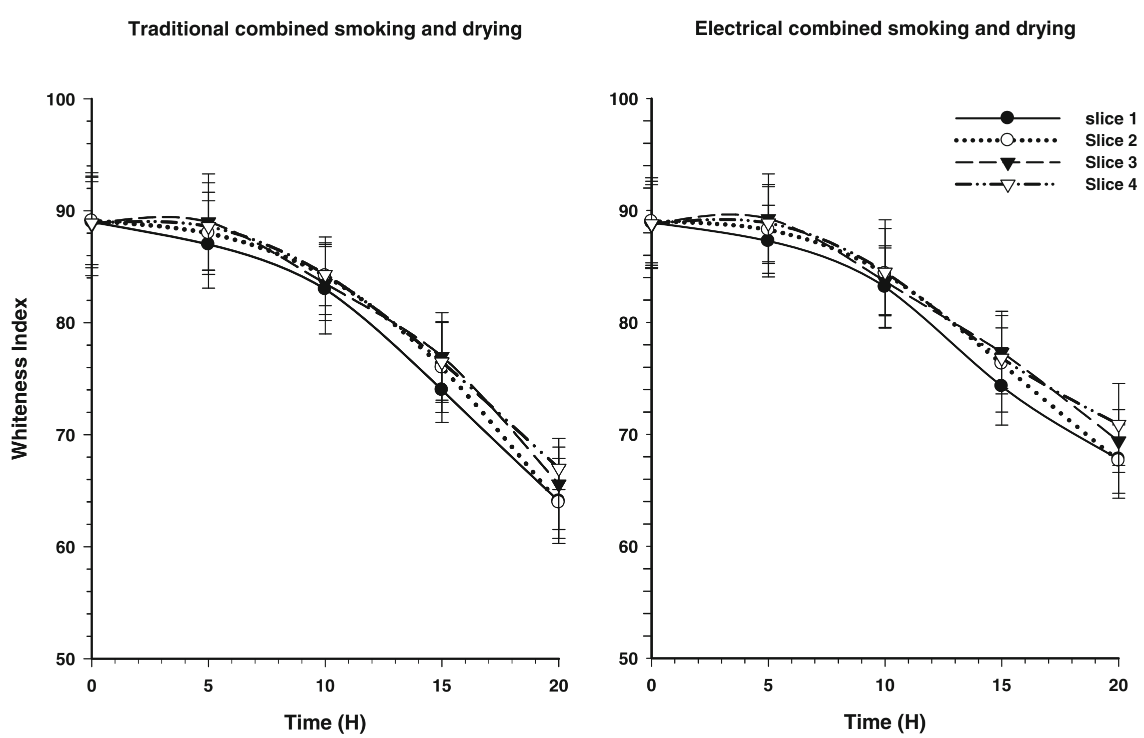


Fig. 4 Smoking kinetics of cassava slices for traditional and electrical combined smoking and drying processes

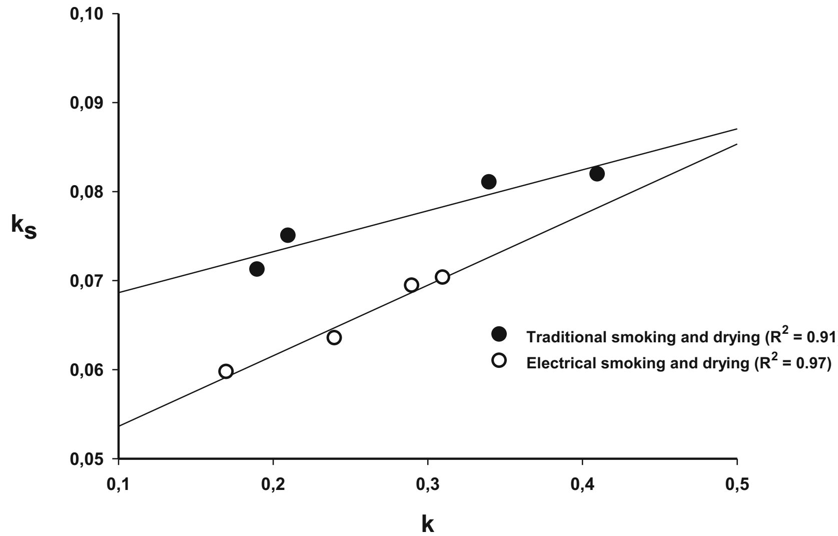


Fig. 5 Correlation between drying (k) and smoking (k_s) constants of fufu ball slices from traditional and electrical combined smoking and drying methods

Pasting temperatures varied between 68.5 and 71 °C for both retted flours and starches. These temperatures are indicative of the minimum energy required to initiate rapid absorption of water and swelling of starch granules resulting in increased viscosity and formation of the dough. In other words, pasting temperature gives an indication of the minimum temperature for cooking of a given sample. The fact that there was no significant difference between starch and flour pasting temperature confirms that this parameter depends more on starch content than on other flour components. Moorthy et al. (1992) reported that unless it is high, fibre content in cassava flour could not induce the elevation in the pasting temperature. The current result is also similar to the results of Osundahunsi and Oluwatooyin (2005) on pupuru—a Nigerian smoked and dried fermented cassava product. However, Dufour et al. (1995) found a pasting temperature value of 62.5 °C in three sour starches from three cassava varieties. This sour starch was dried at 40 °C. Differences observed in pasting temperatures—between the above sour starch and the retted starch of this study—could be related to a partial hydrolysis of starch during souring process. In addition, the drying temperature level could be another source of differentiation. Crosbie and Ross (2009) showed that the starch drying temperature is positively correlated with its pasting temperature. Therefore, the starch drying temperature influences positively the pasting temperature; when the first is high, the latter will also be high and vice versa. Concerning the functional utilization of flour and starch, the relatively high peak viscosity exhibited by all samples is indicative that the flour may be suitable for food products requiring high gel strength and elasticity (Maziya-dixon et al. 2005).

Extracted starch paste showed higher peak viscosities (3,579–4,088 mPa s) when compared to flour dough (3,259–3,372 mPa s). Peak viscosity attained during the heating portion of the test indicates the water binding capacity of starch mixtures, which is also the maximum attainable viscosity in the suspension during cooking. It

Table 4 Proximate composition of retted flours and starches from three drying methods

Composition	Fresh tubers	Traditional combined smoking and drying		Electrical combined smoking and drying		Oven-drying	
		Flour	Starch	Flour	Starch	Flour	Starch
Ash (% DW)	2.8±0.1[a]	1.4±0.2[b]	0.5±0.2[c]	1.5±0.1[b]	0.5±0.0[c]	1.6±0.0[b]	0.5±0.1[c]
Soluble carbohydrate (% DW)	3.1±0.5[a]	2.6±0.1[b]	0.1±0.0[c]	2.4±0.1[b]	0.2±0.0[c]	2.8±0.3[b]	0.1±0.0[c]
Crude fibre (% DW)	5.1±0.7[a]	3.7±0.1[b]	0.7±0.1[c]	3.7±0.3[b]	0.5±0.1[c]	3.7±0.6[b]	0.6±0.0[c]
Protein (% DW)	1.1±0.1[a]	1.9±0.1[a]	1.2±0.0[b]	1.9±0.1[a]	1.2±0.0[b]	1.9±0.0[a]	1.2±0.0[b]
Crude fat (% DW)	1.1±0.2[a]	1.2±0.1[b]	ND	1.5±0.0[c]	ND	1.1±0.0[b]	ND
Starch (% DW)	69.5±0.5[a]	62.5±0.7[b]	96.6±0.4[c]	64.7±2.7[b]	95.9±0.7[c]	63.3±0.8[b]	96.4±1.3[c]
HCN (mg/100 g DW)	14.0±0.7[a]	0.37±0.0[b]	ND	0.4±0.05[b]	ND	0.40±0.0[b]	ND

Values in the same line without the same letter(s) are significantly different ($p \leq 0.05$)

ND not detected

Table 5 Pasting properties of cassava flour and starch obtained by three drying methods

	Drying methods*	PV (mPa s)	Lowest HPV (mPa s)	BD (mPa s)	SB (mPa s)	CPV (mPa s)	CS (mPa s)	PT (°C)
Flour	Traditional combined smoking and drying	3,372±101^{a}	2,581±189^{a}	791±91^{a}	817±37^{a}	4,189±145^{a}	1,608±83^{a}	70.95±1.2^{a}
	Electrical combined smoking and drying	3,350±117^{a}	2,064±111^{b}	1,286±103^{b}	27±5^{b}	3,377±121^{b}	1,313±92^{b}	70.55±1.3^{a}
	Oven-drying	3,259±96^{a}	2,156±174^{b}	1,103±98^{b}	312±13^{c}	3,571±108^{b}	1,415±97^{b}	70.46±1.1^{a}
Starch	Traditional combined smoking and drying	4,088±124^{b}	2,475±191^{a}	1,613±74^{c}	−52±15^{d}	4,036±79^{a}	1,561±127^{a}	70.86±1.3^{a}
	Electrical combined smoking and drying	3,579±107^{c}	1,757±178^{b}	1,822±57^{d}	−839±34^{e}	2,740±81^{c}	983±102^{c}	69.67±1.7^{a}
	Oven-drying	4,072±112^{b}	2,314±186^{a}	1,758±58^{c}	−489±28^{f}	3,583±67^{b}	1,269±116^{b}	68.58±1.5^{a}

Viscosity values in the same column without the same letter(s) are significantly different ($p \leq 0.05$)

PV peak viscosity, *HPV* hot paste viscosity, *BD* breakdown, *SB* setback, *CPV* cool paste viscosity at 50 °C, *CS* consistency, *PT* pasting temperature

determines hot paste handling ability, that is, it provides an indication of the viscous load likely to be encountered during mixing. Thus, for all drying methods, flour dough with lowest peak viscosity values was easier to handle than the corresponding starch paste. The fact that starch dough was more viscous than its corresponding flour dough could be due to the influence of the other flour components. The flours exhibited high fibre, lipid and protein contents when compared to starches (Table 4). These components interact with the starch in the flour and affect its measured viscosity in the RVA. Crosbie and Ross (2009) reported that some non-starchy components reduce the viscosity of the paste by interfering with the starch swelling during the test.

The lowest hot paste viscosity HPV (or trough viscosity) and the breakdown viscosity are other two important pasting parameters. The HPV means the trough at the minimum hot paste viscosity, and it is influenced by the rate of amylose exudation, granule swelling and amylose–lipid complex formation (Kaushal et al. 2012), while the breakdown viscosity is the difference between the peak viscosity and the lowest hot paste viscosity. Through and breakdown viscosities indicate the paste resistance to disintegration in response to heat and shear. It is well known that the lower breakdown viscosity indicates the higher stability of the end product. According to this study, overall breakdown results showed that starch paste had the highest breakdown values comparably to flour pastes. Therefore, starch dough presented less shear stress stability at hot temperature than flour dough. The level of fibres in flour allowed the dough to withstand the shearing at hot temperature. Yildiz et al. (2013) found that as the fibre concentration increases, the HPV and breakdown viscosity values increase. The traditionally smoked and dried flour and starch doughs exhibited the smallest breakdown values (791 and 1,613 mPa S, respectively) when compared to other flour and starch paste, respectively. Thus, the traditional fufu paste shows a hard and cohesive texture than the paste from the two other processes. These data confirm those related to the consistency values of this study. The current result is in agreement with other studies (Osundahunsi and Oluwatooyin 2005).

The final viscosity or CPV is the most commonly used parameter to determine a particular starch-based sample quality. It gives an idea of the ability of a material to gel after cooking. In other words, final CPV is the change in the viscosity after holding cooked flour or starch at 50 °C, and it represents cooked flour/starch stability. This parameter allows the calculation of the CS also called gel index. The CS is the difference between the final viscosity on cooling and the minimum viscosity at hot temperature. The CS values indicated that the traditionally smoked-dried flour and starch were more consistent in texture than their analogues from electrical drying methods. Traditionally smoked and dried flour and starch showed the highest final viscosity when cooled to 50 °C (4,189 and 4,036 mPa s). These results are contrary to those found by Osundahunsi and Oluwatooyin (2005) on some cassava cultivar flours. The cassava botanical origin and their amylose/amylopectin ratio could explain the above differences (Nuwamanya et al. 2010). Each cassava variety develops its own viscosity behaviour.

The setback, as the difference between the final cold viscosity at 50 °C and the peak viscosity, has been reported to correlate with ability of starch to gel into semisolid pastes

Table 6 Cooking time parameters for cassava retted starch paste

	Traditional combined smoking and drying	Electrical combined smoking and drying	Oven-drying
Pt (s)	164±4^{a}	158±3^{a}	134±4^{b}
PVt (s)	324±3^{a}	310±1^{b}	324±2^{a}
CA (s)	160±5^{a}	152±3^{a}	190±3^{b}

Values in the same line without the same letter(s) are significantly different ($p \leq 0.05$)

Pt pasting time, *PVt* peak viscosity time, *CA* cooking ability (food product texture). The setback represents therefore the viscosity of cooked paste. It is a stage where retrogradation or reordering of starch molecules occurs. High setback is also associated with syneresis or weeping, during freeze/-thaw cycles. In this study, the setback values was negative (−839 to −52 mPa s) for all starch doughs, and positive (27 to 819 mPa s) for all flour pastes. These data show clearly that starch retrograde lesser than flour from which it originates. Zhu et al. (2009) associated the observed changes in the setback viscosity values between starch and flour with the interaction between the fibres and leached amylose at the hydrophobic regions and their binding to the side chains of amylopectin through hydrogen bonding and van der Waals force, which might affect the retrogradation and reassociation during cooling period. It is known that fibres significantly allow the paste to recover viscosity during the temperature drop, followed by the phenomena occurring during the starch retrogradation—syneresis and clarity loss—(Crosbie and Ross 2009). During cooling, the starch glycan chains are entangled with each other and contribute to increasing viscosity of the medium. In this study, traditionally smoked flour and starch dough showed the highest setback value and thus a more pronounced tendency to retrogradation. Retrograded starch formed during the cooling of gelatinized starch is termed type III resistant starch (Worawikunya 2007).

Table 6 presents some pasting temporal parameters such as the cooking ability. Traditional and electrical smoked-dried starch pastes were significantly different from the oven-dried one ($p<0.05$) for the cooking ability parameter. The cooking ability for a starch paste is the period running from the pasting time to the time at which it reaches the peak viscosity. The shorter the time taken to reach the peak, the greater is the cooking ability. Smoked-dried starch is more suitable for cooking (160 and 152 s, respectively) than oven-dried starch (190 s). It is possible that starch granule pregelatinization occurred with some slight differences in each drying apparatus during processes. The relatively high pasting temperatures (68.5 and 71 °C) confirm this statement. These results are similar to those found by Osundahunsi and Oluwatooyin (2005) on pupuru flour. The fact that the smoked flour starch paste takes a short cooking time indicates that it requires little energy for its cooking process (Shittu and Adedokun 2010).

Since the same cassava root variety was used, the significant differences observed above within flour pastes—or starch paste, respectively—for breakdown, setback, HPV, CPV and cooking ability values could have been induced by the intrinsic effect of process materials. Despite the predefined drying conditions, each device may express its own functioning errors that could have influenced significantly the above pasting parameters. Osundahunsi and Oluwatooyin (2005) found similar differences for pupuru flours. Shittu and Adedokun (2010) stated that the significant differences observed in the functional behaviour of the fufu flours may be attributed to the drying methods used.

Conclusion

It appears from this study that the combination of the retted cassava pulp smoking and drying significantly influences the colour and pasting properties of the resulting flour and starch to a certain extent. The cooking of this paste seemed economical in terms of energy consumed in the sense that it exhibited higher cooking ability than dough obtained from the oven-dried paste. The smoke constituents play a major role in the modification of fufu pasting properties. The traditionally smoked-dried starch gave a more stable paste at hot temperature and a more consistent gel in cold conditions.

Smoking was positively correlated to the wet ball drying rate but significantly influenced the coloration of fufu flour and its starch. Despite the fact that the attic temperature was not controlled, fufu flour obtained from traditional combined smoking and drying process showed a comparable proximate composition and thus comparable nutritional value with electrical methods. However, the electrical combined smoking and drying process seems to be the best method for cassava pulp processing, because processing conditions are adequately monitored and derived products present low tendency to retrogradation. Meanwhile, the effect of smoking intensity on organoleptic properties is to be investigated.

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