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EFFECT OF INTERMITTENT FRYING ON FATTY ACIDS, VITAMIN E, LIPID OXIDATION AND ACRYLAMIDE IN OILS AND PLANTAIN CHIPS COLLECTED FROM SMALL- SCALE PRODUCERS IN CAMEROON

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ABSTRACT

Deep-fat frying is susceptible to induce the formation of undesirable products as lipid oxidation products and acrylamide in fried foods. Plantain chips produced by small-scale producers are sold to consumers without any control. The objective of this study was to evaluate the quality of plantain chips from local producers in relation to production process parameters and oils, and to identify the limiting factors for the production of acrylamide in plantain chips. Samples of frying oils and plantain chips prepared with either palm olein or soybean oil were collected from 10 producers in Yaoundé. Quality parameters determined in this study were: fatty acid composition of the oils, determined by gas chromatography (GC) of free acid methyl ester; *trans* fatty acids, determined by Fourier transform infra-red spectroscopy; Tocopherols and tocotrienols as markers of nutritional quality were analyzed by High Performance Liquid Chromatography in isocratic mode. Free fatty acids and acylglycerols as markers of lipid hydrolysis were analyzed by GC of trimethylsilyl derivatives of glycerides. Conjugated dienes, Anisidine value and viscosity as markers of lipid oxidation and thermal decomposition of the oils; acrylamide which is formed through Maillard reaction and identified as a toxic compound in various fried products. Asparagine content of the raw fresh plantain powder was also determined. Fatty acid composition of palm oleins was stable within a day of intermittent frying. In soybean oils, about 57% and 62.5% of linoleic and linolenic acids were lost but *trans* fatty acids were not detected. Soybean oils were partly hydrolysed leading to the formation of free fatty acids, monoacylglycerols and diacylglycerols. In both oils, tocopherols and tocotrienols contents decreased significantly by about 50%. Anisidine value (AV) and polymers contents increased slightly in fried palm oleins while conjugated hydroperoxides, AV and polymers greatly increased in soybean oils. Acrylamide was not detected in the chips. This is explained by the absence of asparagine in the raw plantains, the other acrylamide precursors being present. This study shows that the plantain chips prepared at the small-scale level in Yaounde with palm olein are of good quality regarding oxidation and hydrolysis parameters and the absence of acrylamide. In contrast, oxidation developed with soybean oil whose usage for frying should be questioned. Considering that asparagine is the limiting factor for the formation of acrylamide in plantain chips, its content depending on several factors such as production parameters and maturity stage should be explored.

Key words: frying, plantain, producers, palm olein, soybean oil, oxidation, acrylamide, asparagine

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INTRODUCTION

Frying is a thermal process widely used in Cameroon to produce fried foods highly appreciated by the consumers. Among fried products, plantains (*Musa paradisiaca*) are fairly popular [1]. Their local consumption and exportation have increased over the past years, enabling many small enterprises to improve their incomes. A survey conducted in Yaoundé [2], indicated that refined palm olein and soybean oil are the most frequently used oils to produce chips, the latter being preferred by the Cameroonian consumers. Deep-fat frying is performed intermittently throughout the day by the producers, generally without any control of the temperature of the frying bath. Under these conditions, thermal degradation involving lipid oxidation and Maillard reactions may take place, leading to the formation of various neo-formed compounds. The oil remaining after one working day is often re-used the day after. The frying oils are, therefore, a mixture of fresh oil and oil that has undergone multiple re-using. Due to the loss of nutrients such as unsaturated fatty acids, micronutrients, vitamins and the formation of toxic neo-formed products, the quality of the chips and the frying oils may be a cause for health concern.

Oil deterioration during deep-fat frying includes fatty acid oxidation, hydrolysis, polymerization, cyclization and isomerization, leading generally to the formation of undesirable products. Maillard reaction, the reaction of reducing sugars or carbonyl compounds from lipid oxidation with protein amines, leads to the development of colour and pleasant aroma compounds. It also generates toxic products such as acrylamide and hydroxy-methyl furfural (HMF) [3, 4].

The quality of plantain chips can be guaranteed through the control of the characteristics of the frying oils that may evolve during processing [5-7]. For instance, the formation of lipid oxidation products and the modifications of fatty acid composition and tocol content have been used to assess the performance of frying oils [8-10]. The effectiveness of natural or synthetic antioxidants to retard the deterioration of refined, bleached and deodorized palm olein during deep-fat frying of potato chips has also been studied [11].

However, the dissemination of the results of these researches in terms of good frying practices that can be applied by the small-scale producers is not easy. A first step is to know how the chips are actually prepared and to evaluate the quality of the fried plantain sold to the consumers, depending on the main process parameters. Hence, the objective of this study was to evaluate the quality of plantain chips from local producers in relation to the production process parameters and oils, and to identify the limiting factors for the production of acrylamide in plantain chips.

MATERIALS AND METHODS

Frying oils and plantain chips

Samples of plantain chips and frying oils were collected from 10 major small-scale producers in Yaoundé. The producers were chosen after a survey performed among about 200 street chips sellers. Eight producers out of the 10 were using palm oleins and the 2 others were using soybean oils. The samples were collected on the same day at the

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beginning of the working day (T0) and after 3 h, 6 h and 9 h of intermittent frying; the oils being continuously heated as usually done by the producers. Simultaneously, data related to the processing parameters were recorded (Table 1). Producer 5 and 6 added oil during the frying process; producer 6, 7 and 9 used salted plantain; plantain slices were regular (2 mm) except for producers 4 (1.5 mm) and 7 (2.5 mm); Plantain Unit (U) weighed 300 - 350g. The frying oils were filled into 10 mL hermetically sealed tubes. The chips were vacuum-packed with oxygen absorbers (ATCO FT 100/200) in 120 µm polyamide/polyethylene bags (ref. MX5, Imprisac, Vendôme, France) and kept between 4 and 5°C. They were then ground and the ground samples put into tightly closed glass tubes. Frying oils and ground chips were kept frozen at -20°C until physicochemical analysis.

Other materials and chemicals

Raw plantains used for asparagine determination and to explain acrylamide formation were occasionally bought from a supermarket in Napoli (Italy). All the solvents and reagents used in this study were of analytical grade.

Fatty acid composition

The fatty acid composition of the frying oils was determined by gas chromatography (GC) of fatty acid methyl esters (FAME) prepared by transmethylation with BF_3/methanol at 100°C for 45 min [12]. These FAME were injected in on-column mode into the injector (250°C) of a gas chromatograph (Hewlett Packard 5890 Series II) and separated on a polar fused silica capillary column (J&W Scientific ZB-WAX plus, length 30 m, internal diameter 0.32 mm, film thickness 0.25 µm). The carrier gas was hydrogen at a flow rate of 2 mL/min. The temperature programme was as follows: 50°C for 3 min, heating at 15°C/min up to 190°C, 10 min hold, heating at 15°C/min up to 240°C, 240°C for 10 min. The flame ionization detector (FID) set at 250°C was fed with air and hydrogen at flow rates of 250 and 25 mL/min, respectively. Fatty acid methyl esters were identified by comparison of their retention times with those of authentic reference standards (Supelco 37 ref; 47885-U). Peak areas were integrated, the surface of every integrated peak normalized by the surface area at T0 of the peak corresponding to the main saturated fatty acid, that was assumed not to evolve during frying. The results were expressed as mg fatty acid per 100 mg of total identified fatty acids at T0. The analyses were done in triplicate.

Determination of Tocopherols and Tocotrienols

Tocopherols and tocotrienols in the frying oils were analyzed by High Performance Liquid Chromatography in isocratic mode (mobile phase: n-hexane/ter-butyl methyl-ether; 90/10; v/v) with fluorescence detection (Kontron SFM 25; excitation / emission: 295nm / 330 nm) [13], as described by Kansci *et al*. [14]. The amounts of tocopherols and tocotrienols were summed up to obtain the vitamin E concentration in the oils (mg/kg).

Determination of free fatty acids and partial glycerides

Free fatty acids (FFA), mono- di- and tri-acylglycerides were analyzed by GC of trimethylsilyl (TMS) derivatives of glycerides. About 200 µg of oil was derivatised with 100 µL of pyridine/N,O-bis-triméthyl-silyl-acétamide (2/1 ; v/v) for 30 min at room

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temperature. One µL of this solution was injected in on-column mode in a gas chromatograph (Hewlett Packard, HP 5890) equipped with a deactivated silica pre-column of 50 cm length, a capillary column with non polar phase (5%-Phenyl)-methylpolysiloxane (DB-5HT): length 15 m; diameter 0.32 µm ; phase thickness 0.1 µm) and a FID (350°C). Hydrogen at 2 mL/min was the gas vector. The TMS derivatives were eluted with the following temperature gradient: 100°C for 1 min, then 15°C/min until 350°C and finally 350°C for 2 min. The TMS derivatives, separated according to their molecular weight, were identified by comparison of their retention times with those of authentic standards of free fatty acids, mono- di- and triacylglycerides (Sigma). The corresponding peaks were integrated with the Borwin software and expressed as percentages of the total peak areas. Finally, the proportions of free fatty acids, monoacylglycerols (MAG), diacylglycerols (DAG) and triacylglycerols (TAG) in total identified species were calculated. A single analysis was done on samples from 8 producers who used palm olein and the 2 who used soybean oil.

Analysis of lipid oxidation products in the oils

Conjugated dienes (CD) were analyzed by UV-Vis spectrophotometry (Lambda 12, Perkin Elmer) with n-hexane as solvent (5 mg oil /mL solvent). Results were expressed as equivalent conjugated hydroperoxides (mmol/kg oil) with the molar extinction coefficient 27000 $M^{-1}.cm^{-1}$ at 233 nm [15]. Single analyses were performed.

Anisidine Value (AV) was determined according to the standard ISO 6885 modified method [16]. Analyses were done in triplicate on the samples from all producers.

The formation of polymers in the oils was estimated by measuring their viscosity (Pa.s) at 25°C [17]. A cone-plane rotative viscosimeter (RFS 2, Rheometrics) equipped with a 50 mm, 0.04 radian cone with a truncature of 0.05 mm was used. A single analysis was done on the samples obtained from all producers.

***Trans* fatty acids in fried oils**

The presence of *trans* fatty acids in the fried oils was appreciated by Fourier transform infra-red spectroscopy [18]. The infrared spectra were recorded at room temperature between 400 and 4000 cm^{-1} at 2 cm^{-1} intervals (200 scans) with a Fourier transform infra red spectrometer (Vector 22, Bruker) in attenuated reflectance (ATR) mode. Three hundred (300) µL of oil were poured on the cell made of a ZnSe crystal allowing six internal reflections. A baseline was recorded on the air before each measurement. The cell was thoroughly cleaned with hexane and ethanol between each sample. The spectra were smoothed (17 points), corrected from the baseline and normalized (vectorial mode) with the apparatus software (OPUS 2.0). The formation of *trans* fatty acids was evaluated from the absorbance at 966 cm^{-1}. A single analysis was done on the samples from all producers.

Quantification of acrylamide in plantain chips

Acrylamide in plantain chips was analyzed by LC-MS-MS [19]. The High Performance Liquid Chromatographic system (Perkin Elmer series 200) used was equipped with 2 micro pumps, an autosampler coupled to a MS/MS detector (API 3000 LC/MS/MS, model AB) equipped with a Turbo ion spray. Samples were prepared according to

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Capuano *et al.* [20]. The limit of quantification of the method was 5 $mg.kg^{-1}$. A single analysis was done on the samples from all producers.

Determination of asparagine in plantains

Raw fresh plantains were peeled with a knife and the slices freeze-dried and ground. The asparagine content of the plantain powder was determined by LC-MS using an enzymatic kit (EZ:faast kit packaging for amino acid analysis, Phenomenex, Torrance, USA). Briefly, 14 mL of water/ethanol (50/50; V/V) were added to 0.2 g sample. The mixture was agitated at 50°C for 20 min and then centrifuged at 4000 rpm for 20 min. One hundred (100) µL of supernatant was used as indicated in the kit. A EZ:faast AAA-MS column 250 x 3.0 mm was used and the separation was done by the mobile phase consisting of 10 mM ammonium formate in water (A) and 10 mM ammonium formate in methanol (B), at a flow rate of 0.5 mL/min at 35°C. The limit of detection of the method is 100 $mg.kg^{-1}$ and the recovery is 75%.

Asparagine spiking experiments in plantains

To verify the role of plantain composition on the acrylamide formation a spiking experiment with asparagine was performed. Asparagine (Asn) powder (1 mg) or asparagine solution (50 µL, 1 mg/mL) was added to 500 mg of the freeze-dried plantain powder. The three powders (plantain powder = control, plantain powder + Asn powder and plantain powder + Asn solution) were heated at 180°C for 20 min in an oven. Acrylamide was determined in the heated powders as previously described.

Statistical analysis

The results of the analysis performed on the samples of plantain chips coming from the local producers and of the palm oleins and soybean oils are reported separately as means +/- standard deviations. Analysis of variance (ANOVA) and comparison of means (Neuman-Keuls test; $p<0.05$, otherwise stated) were performed with Statgraphics software package. When comparison of variance test detected differences in standard-deviations according to tested groups, the results of non parametric Kruskal-Wallis test were considered.

RESULTS

Fatty acid composition of the oils

In the oils collected before frying (T0), saturated (SFA), monounsaturated (MUFA) and polyunsaturated (PUFA) fatty acids were about 44, 45, 11 % and 18, 27, 54 % of total fatty acids for palm oleins and soybean oils, respectively, which is within the normal range of fatty acids (FA) composition of these oils [8, 14]. The evolution of the fatty acyl residues of the oils collected from producers at T0 and after 3h, 6h and 9h of intermittent frying is shown in Fig. 1 and 2. The fatty acid composition of palm oleins was stable, with the saturated, monounsaturated and polyunsaturated being unchanged (Fig. 1). For example, C18:1 n-9 which is the main fatty acid of palm olein remained constant within a day of intermittent frying as did C18:2 n-6 and C18:3 n-3. A different trend was observed with soybean oil with a significant effect of frying ($p<0.01$) (Fig. 2). After frying, total FAs were reduced by nearly 40%. Saturated fatty acids remained constant, while unsaturated FAs were destroyed. Linoleic acid, which was about 48.5

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mg/100 mg total fatty acids at T0, decreased to 21 mg/100 mg at T3, T6 and T9. Linolenic acid also decreased from 6.4 mg/100 mg to 2.4 mg/100 mg without any significant effect of the duration of the intermittent frying (3h, 6h or 9h of frying). Oleic acid also decreased from 27 mg/100 mg to 20 mg/100 mg total fatty acids.

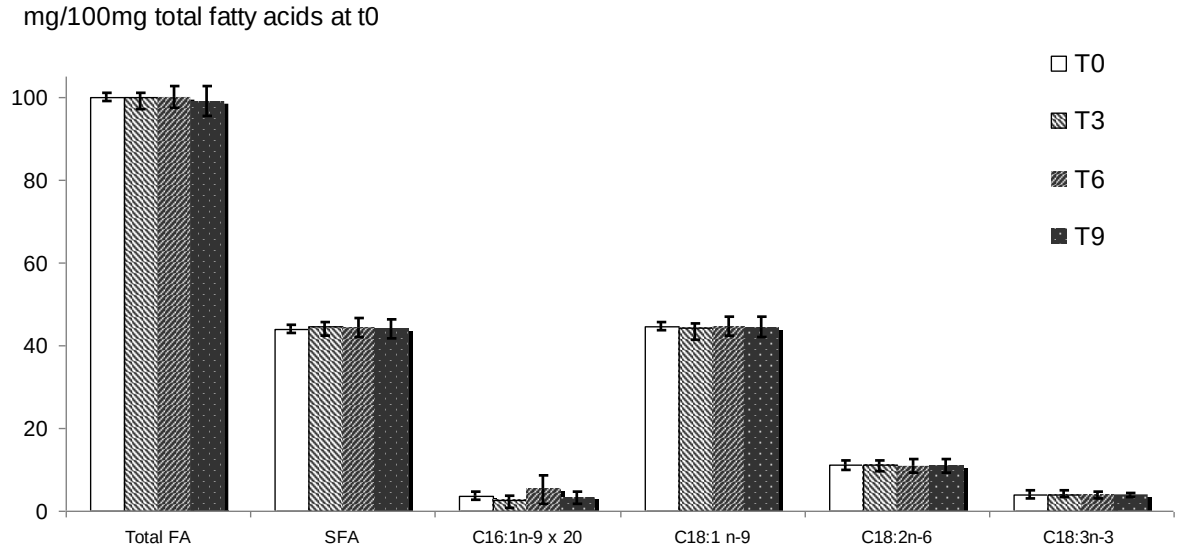

Figure 1: Evolution of fatty acid composition of palm oleins collected at different small-scale producers during one day of intermittent frying of plantain chips. T0, T3, T6 and T9 are collection times, respectively 0h, 3h, 6h and 9h

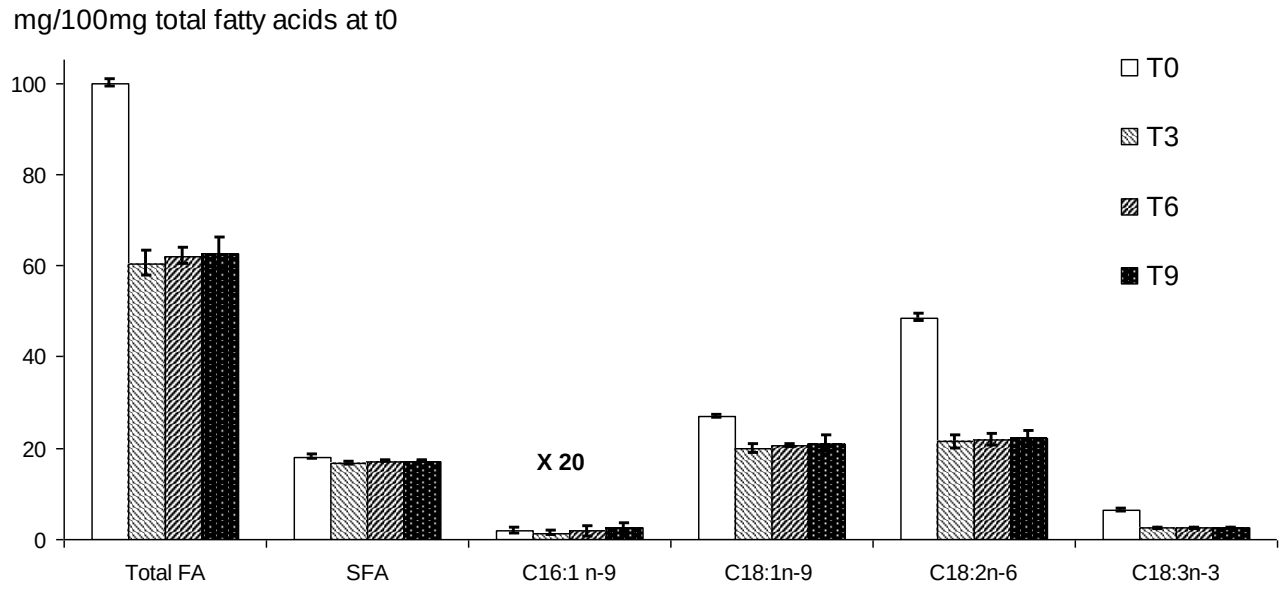

Figure 2: Evolution of fatty acid composition of soybean oils collected at different small-scale producers during one day of intermittent frying of plantain chips. T0, T3, T6 and T9 are collection times, respectively 0h, 3h, 6h and 9h

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***Trans* fatty acids**

Palm oleins and soybean oils collected before frying exhibited absorbances at 966 cm^{-1} equal to 0.07 and 0.08, respectively (Table 2 & 3). These values did not change significantly in the samples collected after 3h and 9h of intermittent frying, suggesting that no change in the *trans* fatty acid content of the oils occurred in the oils during frying.

Tocopherol and tocotrienol contents

The vitamin E sum of tocopherols and tocotrienols content of the oils collected before frying varied enormously. It varied from 321 to 607 and from 1101 to 1225 µg/g, respectively for palm oleins and soybean oils with mean values of 464 ± 143 µg/g and 1163 ± 62 µg/g (Tables 2 & 3). A significant decrease of the mean vitamin E content of the oils just after 3 h frying was observed. With palm oleins, the effect of frying time on vitamin E content was important, the mean concentration decreasing to 282 µg/g after 3 h frying and to 191 µg/g after 9 h frying (Table 2). Vitamin E content did not decrease upon intermittent frying time for producer 8 and decreased only between T0 and T3 for producer 5 that added fresh oil during the frying day. In contrast, for producer 2 the vitamin E content of the oil was already low at T0 (about 260 mg/kg) and only low amounts of delta-tocopherol and delta-tocotrienol being detected at the latter stages, alpha and beta isomers of tocopherol being undetected; a similar observation was only made for the sample from producer 3 at T9. The decrease of the vitamin E content in soybean oils was more moderate: it reached 738 µg/g after 3 h of frying and 618 µg/g after 9 h frying, with values similar to the samples taken from one producer or the other (Table 3). After one day of intermittent frying, only 40% or 53% vitamin E remained (mean values) in the oils for producers using palm olein (2 to 80%, depending on the producer) or soybean oil, respectively (Tables 2 & 3).

Conjugated Dienes (CD)

The initial level of conjugated dienes of the oils collected before frying (T0) was 14 ± 4.4 and 10 ± 5.5 µmol/g for palm oleins and soybean oils, respectively (Tables 2 & 3) with variation from one producer to another. After frying with soybean oils, CD increased significantly, up to 24 ± 11 µmol/g after 9 h of intermittent frying (Table 3). With palm oleins, CD, initially higher than in soybean oils, remained significantly constant all along the intermittent frying.

Anisidine Value (AV)

Anisidine value of oils collected from various producers (Tables 2 & 3) at the beginning of the working day was higher in palm oils, with large variations within samples (11 ± 10) compared to soybean oils (1.5 ± 0.6). The highest value was measured at T0 (27.8 ± 0.9) for the oil sample from producer 3, followed by the oil from producer 7 (22.1 ± 0.1). After intermittent frying, large variations of anisidine values were also observed within palm olein samples (Table 2). A great increase in AV was observed in fried soybean oils (37.9 at 3h) and an effect of intermittent frying time was also noticed (AV at T9: 58 ± 4.9) (Table 3). Anisidine values also increased with palm olein as frying oil, without any significant effect of intermittent frying time in reason of the large variations between the samples according to the producer (Table 2).

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Polymers

Before frying, viscosities of the oils collected ranged from 64 to 49 mPa.s for palm oleins and soybean oils, respectively. After frying, a significant increase of the viscosity was observed for palm oleins (68 mPa.s); with no significant effect of the frying time (Table 2). The increase of the viscosity was much important after frying with soybean oil (57 mPa.s), with a significant effect of frying time (60 mPa.s at 9 h) (Table 3).

Glyceride composition of the oils

The oils collected before frying (T0) contained 93.5% of TAG for palm oleins against 98.2% for soybean oils. Also, a high proportion of DAG (6%) was found in palm oleins but only 1.5% in soybean oils. Soybean oils were characterized by more FFA: 0.065% against 0.046% in palm oleins. After frying, a decrease in TAG was observed for both oils, with an increase in DAG, MAG and FFA in soybean oils. At the end of the frying day, the FFA and MAG of soybean oils significantly decreased again (0.22% after 9 h for MAG and 0.06% for FFA). This decrease was also observed with MAG and FFA of palm oleins (0.21% for MAG and 0.04% for FFA at T9) (Tables 2 & 3).

Acrylamide

No acrylamide was detected in the plantain chips collected from the producers, whatever the oils used and intermittent frying time (Fig. 3). The amount of asparagine (Asn) in the raw plantains used in this study was also below the limit of quantification of the method. To confirm that acrylamide formation in plantain depends on the presence of asparagine [4, 20], the compound was added at different concentration to dried plantain samples which were then heated in an oven at 180°C for 20 min. The results reported in Figure 3 evidence a low concentration of acrylamide (162.9mg.kg^{-1}) in the oven-heated plantain powder. When asparagine was added to the plantain powder, the oven treatment induced instead formation of high concentration of acrylamide in the oven-heated plantain (Fig. 3). This shows that among the precursors of acrylamide [4], asparagine was the limiting factor in the plantain samples used in this study.

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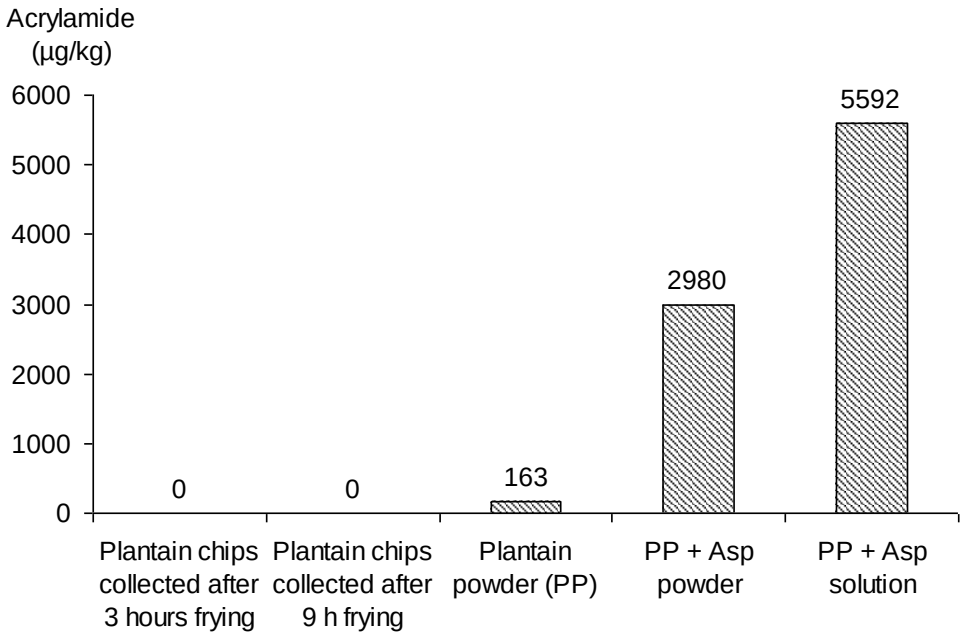

Figure 3: Concentration of acrylamide in plantain chips collected at 3 h or 9 h of intermittent frying with palm olein or soybean oil; in plantain powder heated for 20 min at 180°C and in the plantain powder heated in the presence of asparagine (Asp) powder or solution

DISCUSSION

Fatty acids oxidation of the oils during intermittent frying of plantain

The quality of frying oils generally reflects the quality of the lipids inside the fried food [8, 9] due to fast exchange of fats during frying. Intermittent frying leads to the decrease in unsaturated fatty acid in soybean oil. The more the degree of unsaturation of the FA, the higher their oxidative degradation, as previously noticed with canola oil [9]. The unsaturated fatty acids did not disappear in the palm oils in which they were initially present in lower amounts. When the unsaturated fatty chains were accompanied by high amounts of saturated fatty chains, they seemed to be protected from oxidative and/or thermal degradation. The decrease of MAG and FFA of the oils could be explained by their higher sensitivity to oxidation during intermittent frying or their preferential absorption by the plantain chips.

The high increase of AV in soybean oil is in line with the increase of CD in this oil and with the decrease of unsaturated fatty acids due to oxidation [21]. These results confirm the inadequacy of soybean oil for frying compared to palm olein. Similarly a significant temperature-dependant increase in AV during frying of potato chips in cottonseed oil has been observed [22]. Using canola oil, an increase in the anisidine value has also been reported, with a maximum on the second day of frying [9]. Anisidine value, which is used to quantify secondary oxidation products of oils such as 2,4-dienals is a sensitive method [5**].** In this study the researchers did not measure selectively undesirable neo-formed reaction products typically produced during frying of oils. Anisidine value gives

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an indication of the possible formation of compounds such as alpha, beta unsaturated aldehydes during the frying process. The slow increase of the viscosity of palm olein during intermittent frying confirms the stability of this oil under the conditions used by producers of plantain chips in Cameroon compared to soybean oil. The increase of the viscosity here corresponds to the formation of polymerised compounds with high molecular weight [23].

The large variation of Vitamin E content of the oils can be explained by the diversity of the oils used by the producers and the storage conditions before using. Most of the palm oils used were produced by different small-scale and large-scale local enterprises without quality control. The low final concentrations of the antioxidant tocopherol isomers did not correlate with any quantitative loss of polyunsaturated fatty acids in the corresponding samples. A significant decrease of the mean vitamin E content of the oils just after 3 h frying could indicate the fast degradation of tocopherols and tocotrienols during frying with both oils. However, a blend of palm olein and soybean oil could improve the stability and nutritional quality of frying oils as proposed for canola oil and palm olein [8]. This practice is usually done by the producers.

Unfavorable *trans* fatty acids in oils and acrylamide in plantain chips during intermittent frying

Results indicate that *trans* fatty acids remained minor constituents of the oils used by the plantain chips producers. These unfavorable compounds may be present in frying oils and in plantain chips at low levels, which is below the limit of detection of the method. *Trans* isomerization of double bonds can occur during frying of foods with oils rich in unsaturated fatty acids [18]. The increase in the *trans* fatty acid content of canola oil has been shown to depend on frying temperature and time, with the content in *trans* isomers increasing 2.5 times during frying at 215°C [9]. Increased amounts of *trans* isomers during frying at high temperature have practical implications related to nutritional claims about zero trans content in a serving portion of fried products. One may assume that the moderate temperatures attained during the intermittent frying as performed by the Yaounde's producers (maximum recorded temperature = 160°C; Table 1) limited the formation of this unfavorable compound.

French fries and potato chips are the main acrylamide contributors in fried products. The amount of acrylamide in these products ranges from 100 $mg*kg^{-1}$ in pale yellow product up to 2000 $mg*kg^{-1}$ in brown well done potato crisps [24]. The results on acrylamide contents in plantain chips clearly confirm that free asparagine is the limiting factor for the formation of acrylamide in plantain chips [19]. Actually, asparagine contents of samples in the present study is in the low rank, considering the value for asparagine in plantains reported by other authors, that is 0-73 mg/100 g of dry weight for raw plantain [25]. According to these authors, although at a lesser extent than "dessert bananas", fried plantains have also the potential to form acrylamide during frying. One should also notice that the frying temperatures used by the producers of the collected plantain chips (generally between 95 and 140°C, maximum recorded temperature at the beginning of the process: 180°C) were less severe than the oven treatment, as indicated in Table 1. Acrylamide has been previously measured in fried products, including plantains [26]. However, in the study of Quayson and Ayernor [26], the acrylamide formation was

estimated by optical density and the method could have led to overestimation of the actual amounts compared with updated analytical methodologies. In this respect, data obtained here show that the formation of acrylamide is not a concern in plantains having low amount of free asparagine and fried at moderate temperature. However, the control of asparagine content in the foodstuff through the selection, the maturity stage or by implementing immersion pre-treatments should be ensured [27].

CONCLUSION

This study evaluated the quality of oils used for intermittent frying and of plantain chips collected from small-scale producers in Yaoundé. Results show that the plantain chips prepared at the small-scale level in Yaounde with palm olein are of good quality regarding oxidation and hydrolysis parameters and the absence of acrylamide. In contrast, oxidation developed with soybean oil whose usage for frying should be questioned. A large variation of Vitamin E content of the oils can be explained by the diversity of the oils used by the producers and the storage conditions before using. Considering that asparagine is the limiting factor for the formation of acrylamide in plantain chips, its content which depends on several factors such as production parameters and maturity stage should be explored.

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Table 1: Frying conditions registered during sampling of oils and plantain chips from 10 producers in Yaounde

Producer N°	Oil used	Oil/Plantain ratio (V/U)	Frying temperature (Beginning/ End)	Frying time (min)	Maturity of plantain
1	Palm olein	5L/5	105°C /105°C	15	Ripe and unripe
		4L/3	125°C /150°C	9	
		2L/3	80°C /110°C	10	
2	Palm olein	6.5L/5	125°C /150°C	40	Ripe
		5L/5.5	98°C /120°C	33	
		4L /5.5	95°C /125°C	47	
3	Palm olein	8.2L/6	100°C /125°C	37	Ripe
		7L /5	100°C /120°C	15	
		6L/4	115°C /120°C	16	
4	Palm olein	5.8/3	100°C /140°C	13	Ripe
		5L /3	110°C /140°C	13	
		3.5/4	160°C /140°C	24	
5	Palm olein	2.6L/2	99°C /140°C	20	Ripe
		4L/4	95°C /145°C	26	
		3.5L/3	95°C /145°C	22	
6	Soybean oil	12L/3	180°C /160°C	10	Unripe
		10L/4	160°C /130°C	15	
		8L/3	170°C /140°C	9	
7	Palm olein	2L/5	110°C /125°C	19	Unripe and slightly ripe
		1.5L/4	105°C /130°C	17	
		1L/3	120°C /130°C	15	
8	Palm olein	2.7L/4	100°C /140°C	25	Ripe
		3L/4	100°C /145°C	20	
		2.5L/3	95°C /145°C	19	
9	Soybean oil	10L/3	170°C /160°C	15	Unripe
		9L/4	180°C /160°C	10	
		7L/4	160°C /140°C	17	
10	Palm olein	5.5L/6	140°C /130°C	42	Ripe
		4L/6	150°C /130°C	41	
		3L/4	110°C /130°C	30	

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Table 2: Evolution of the quality of refined palm olein during one day of intermittent frying of plantain chips by Cameroonian small-scale producers: vitamin E content (Vit E), conjugated dienes (CD), anisidine value (AV), *trans* fatty acids (absorbance at 966 cm^{-1}), viscosity and glyceridic species (% total lipids)

Time hours	Vit E µg/g	CD µmoles/g	AV	*trans*-FA A966 cm^{-1} x10^3	Viscosity mPa.s	Free fatty acids and glyceridic species % total species			
						FFA	MAG	DAG	TAG
	n=8 p=0.0194	n=7 p=0.698	n=8 p=0.094	n=8 p=0.60	n=8 p=0.0683	n=4 p=0.81	n=4 p=0.45	n=4 p=0.36	n=4 p=0.27
0	464±143[a]	14±4.4	11±10[a]	7.57±0.27	64.0±6.0[A]	0.046±0.02	0.42±0.36	6±2.3	93.5±1.9
3	282±159[ab]	14±3.3	21±17[ab]	7.16±0.11	68.0±2.0[B]	0.037±0.23 *	0.43±0.21	7.4±0.6	92.0±0.6
6	263±190[ab]	15±4.1	25±21[ab]	7.30±0.26	68.0±2.0[B]	0.062±0.57	0.29±0.085	7.1±0.3	92.5±0,3
9	191±169[b]	16±4.5	32±29[b]	7.19±0.26	68.0±2.0[B]	0.045±0.035	0.21±0.09	7.2±0.3	92.6±0.3

In a column, data superscripted with the different letters are statistically different at the 5 % (normal letter) or 10 % (capital letters) threshold; Neuman-Keul test

* n=3

FFA= free fatty acids; MAG= monoacylglycerols; DAG= diacylglycerols; TAG= triacylglycerols

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Table 3: Evolution of the quality of refined soybean oil during one day of intermittent frying of plantain chips by two Cameroonian small-scale producers. Vitamin E content (Vit E), conjugated dienes (CD), anisidine value (AV), *trans* fatty acids (absorbance at 966 cm^{-1}), viscosity and glyceridic species (% total lipids)

Time **Hours**	Vit E µg/g	CD µmoles/g	AV	*trans*-FA A966 cm^{-1} x10^3	Viscosity mPa.s	Free fatty acids and glyceridic species % total species			
						FFA	MAG	DAG	TAG
	P=0.0007	p=0.51	p=0.000	p=0.81	p=0.0004	p=0.048	P=0.0092	p=0.016	p=0.011
0	1163±62^{a}	10±5.5	1.5±0.63^{a}	8.4±0.7	49.5±0.6^{a}	0.065±0.007^{A}	0.21±0.035^{a}	1.5±0.11^{a}	98.2±0.16^{a}
3	738±35^{b}	17±6.4	37.9±0.7^{b}	7.7±0.6	57.6±0.7^{b}	0.13±0.028^{B}	0.35±0.007^{b}	3.7±0.13^{b}	95.8±0.11^{b}
6	678±16^{b}	19±11	44±1.2^{c}	8.5±1.3	58.3±0.1^{b}	0.115±0.007^{AB}	0.34±0.007^{b}	3.5±0.2^{b}	96.0±0.21^{b}
9	618±16^{b}	24±11	58±4.9^{d}	8.5±0.9	60.3±0.1^{c}	0.065±0.021^{A}	0.22±0.035^{a}	4.3±0.9^{b}	95.4±0.86^{b}

In a column, data superscripted with the different letters are statistically different at the 5 % (normal letter) or 10 % (capital letters) threshold; Neuman-Keul test

FFA= free fatty acids; MAG= monoacylglycerols; DAG= diacylglycerols; TAG= triacylglycerols

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