Kinetics of moisture loss and fat absorption during frying for different varieties of plantain

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Abstract: This study compares the behaviour of four varieties of green plantain at their initial stage of maturity during the frying process. A variety traditionally used for the manufacture of thin plantain chips (Dominico Hartón commun) and three other varieties found in Latin America (Bouroukou, Bluggoe and FHIA 21) were used. The varieties were characterised by measuring initial moisture content, total sugar content, reducing sugar content, starch content and apparent density. Moisture loss and fat uptake kinetics during frying were assessed at different temperatures (145, 165 and 185°C). With all four varieties, the time required to produce a final moisture content of 40 g kg^{-1} (wb) was about 90 s at 165°C and 185°C. Use of a lower temperature (145°C) extended the processing time to 150 s. On the other hand, temperature had very little effect on fat content, which proved to be essentially determined by the variety of plantain. Fat content for final water content levels of 40 g kg^{-1} (wb) ranged from 300 g kg^{-1} (wb) for Bouroukou to 450 g kg^{-1} (wb) for Bluggoe regardless of the processing temperature.

Keywords: plantain, frying, varieties, composition, kinetics, moisture loss, fat uptake, palm oil.

INTRODUCTION

The world snack food market is currently expanding rapidly.[1] For example, the snack food market in the USA, worth US$ 25 billion in 1987, has grown by US$ 10 billion a year over the last ten years.[2] A large part of this market consists of chips or fried products using starch-based raw materials (roots, tubers, bananas and plantains). Such products are obtained by cutting the raw material into fine slices or parallelepipeds, initially a few millimetres thick, then frying them in vegetable oil for a few minutes at high temperature (130 to 180°C at atmospheric pressure).

Frying is a very widespread method of plantain chip production, both for local consumption and for export. In Europe, banana and plantain chips (primarily imported from South-East Asia) are consumed in cocktail mixtures and in breakfast cereals.

Plantain chips are regarded as a popular consumer product in Africa.[3] 'Patacones' and 'tajadas', pieces of green plantain fried in coarse or fine slices cut lengthways or crossways, are very common in Latin America. The latter are produced on a small scale either at home or by street vendors or are manufactured industrially. One of the largest producers of plantains in Latin America is Colombia, which has about 400 000 hectares under cultivation. The country's annual production of approximately 2.5 million tonnes primarily supplies the home market,[4] with only about 200 000 tonnes per year being exported to the American market.[5] A survey conducted using a sample of 170 consumers residing in Cali (Colombia's third-largest city), with very varied standards of living, revealed that 99% of households who prepared home-fried products used plantains, 92% of the population surveyed prepared patacones more than once a week, while 43% bought industrial patacones on a regular basis. This survey also revealed that 87% of consumers of industrial patacones would increase their consumption if product quality were improved.[6]

Despite the volume of fried products consumed throughout the world, aspects related to management of the frying process have up to now been the subject of relatively little research, compared to other production processes. Research into frying has essentially concentrated up to now on oil deterioration kinetics.[7] Little attention has been paid to the effect of the variability of the raw material on its frying behaviour and the physicochemical properties of the final product.[8] There are nevertheless numerous references to the production of fried plantain chips in Latin America, Asia and Africa. The literature

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reports that plantain chips are produced in Venezuela,[9] Costa Rica,[10] Honduras,[11] Colombia, Ecuador,[12] Puerto Rico,[13] Brazil,[14] the Philippines[15–18] Indonesia,[19] Malaysia[20,21] India,[22–25] Nigeria,[3,26] Cameroon[27] and the Ivory Coast.[28] It is difficult, however, to formulate general rules as to the suitability of different varieties on the basis of these studies, since they use different frying conditions.

Only two varieties of triploid AAB plantain are currently used for industrial frying in Colombia: 'Hartón commun' (*Musa paradisiaca* Linneo) and 'Dominico Hartón commun' (*Musa paradisiaca* Simmonds).

The purpose of the present study was to compare the behaviour of four varieties of green plantain: one of the two varieties traditionally used in Colombia, 'Dominico Hartón commun', and three other varieties found in Latin America. The study aimed at characterising the different varieties (apparent density, total sugar content, reducing sugar content, starch content, moisture content) and the frying behaviour of these varieties in terms both of changes in moisture and fat content and of mass yield after processing.

MATERIALS AND METHODS

Plantain preparation

Green plantains from the entire coffee-growing region were used in this study. They were supplied by CORPOICA (Centro Experimental EL AGRADO, situated 1320 m above sea-level). Four varieties of plantain were chosen, taking into account traditional use, availability during the year, size of bunch, size of fruit, agronomic yield and resistance to black Sigatoka (*Mycosphaerella fijiensis*). The varieties tested were selected according to the following criteria:

Dominico Hartón commun (triploid AAB, *Musa paradisiaca* Simmonds): variety traditionally used for the production of fried chips, available throughout the year;

Bouroukou no. 1 (triploid AAB, *Musa paradisiaca* Linneo): variety of African origin, adapted to the climatic conditions of Colombia, with very large fruit;

Bluggoe (triploid ABB, *Musa paradisiaca* Bluggoe): variety traditionally regarded as a cooking plantain, with a more attractive market price;

'FHIA 21' (tetraploid AABB hybrid, *Musa paradisiaca* of the Dominico group): developed in Honduras and used in the industrial frying of patacones, resistant to black Sigatoka, with an extremely high agronomic yield.[29]

The bunch of plantains of each variety was harvested the day before the trials, about 112 days after flowering, and stored in a temperature-controlled chamber (13 ± 1°C). It was kept there for four days at most, and was used as required. The quantity of plantains required for each day of the trials was about one hand, ie from 8 to 12 plantains.

The plantains were peeled by hand. The pulp was sliced into fine rings, $2 \pm 0.1 \times 10^{-3}$ m thick, using a mechanical slicer (SEDALIA MO 65301, Rival MFG Company, USA) with an adjustable cutting disc. The discs were measured with a sliding calliper and any incorrectly sliced were rejected.

The discs were pre-treated before each trial, using the protocol defined by Diaz *et al*,[12] then dried on absorbent paper. Each test sample consisted of a mixture of rings selected from several plantains of the same variety and taken from the same hand.

Frying equipment

The frying trials were conducted using a semi-industrial electric fryer (AFI FT/4, Italy). The frying tank was parallelepiped-shaped and made of stainless steel. Its dimensions were: length 300×10^{-3} m; width 150×10^{-3} m; height 200×10^{-3} m. The bath had an effective volume of 5 litres. It was heated by an 1800 W 26 Ω electrical resistor. The resistor had an area of 0.046 m^2, ie a surface flux of 82.8 W m^{-2}, and was located 35×10^{-3} m above the bottom of the tank.

There was a submerged agitator shaft in the centre of the tank. The shaft was fitted with two flat turbines arranged one above the other at a distance of 50×10^{-3} m, with the lower one located just above the electrical resistor. Each turbine had six blades (external diameter 60×10^{-3} m, blade height 12×10^{-3} m, blade width 15×10^{-3} m). Frying operations were performed with the agitator shaft rotating at a speed of 18.8 rad s^{-1}.

Two removable holders were submerged in the tank, one on either side of the agitator shaft. Each held three hinged stainless steel grids (length 130×10^{-3} m, width 90×10^{-3} m, thickness 10×10^{-3} m) placed horizontally and 10×10^{-3} m apart. The grids had a porosity of 81%.

The temperature of the frying bath was determined by simultaneously measuring the temperatures shown by three K-type thermocouples (CCM-1-250-K, Mesurex, France). The average of the three temperatures was termed the 'reference temperature'. The thermocouples were placed along the tank at mid-depth. They were connected to a data logger (CR10X, Campbell Scientific, Great Britain) and a control panel interface (CR10KD keyboard, Campbell Scientific, Great Britain). The time base for temperature data acquisition by the computer system was 2.72×10^{-3} s. The program then regulated the temperature by sending an electric current to the heating resistor for periods of 0.25 s.

Conduct of the trials

Frying was carried out using refined palm oil, which was renewed every day. Palm oil has the advantage of being very low in polyunsaturated fatty acids (10%) and consequently having good heat and oxidative stability.[30] The frying bath was kept hot all day at the reference temperature.

Five kilograms of palm oil were put in the fryer and heated to the reference temperature TC_h. A total of about 60 g of pre-treated plantain discs were weighed (denoted $m(0)$). The product mass to oil mass ratio (R) was thus very low. The agitator was stopped for a few seconds at start time $t = 0$ to allow the grids containing the samples to be introduced. It was then restarted and ran throughout the processing except at sampling times. The full sample of chips was recovered at time t. The frying trials were conducted at reference temperatures of $T = 145$, 165 and 185°C for $t = 20$, 40, 60, 90, 120 and 150 s. Each frying operation was replicated three times. The chips were placed on absorbent paper to remove the oil remaining on the surface. The cooled chips were weighed (denoted $m(t)$) and their moisture content $MC(t)$ and fat content $FC(t)$ analysed.

Methods of analysis and results

As the varieties used had not previously been characterised, the raw material was characterised before each experiment at a given temperature by measuring its initial moisture content $MC(0)$, total sugar content $C_{\text{tot.sug}}(0)$, reducing sugar content $C_{\text{red.sug}}(0)$, starch content $C_{\text{starch}}(0)$ and apparent density $d_{\text{app}}(0)$. The initial fat content $FC(0)$ was taken from the literature.[31–33]

The total sugar content and the reducing sugar content expressed in dry matter were determined by extraction in a Soxhlet device, using the previously freeze-dried samples. Extraction was performed by entrainment for 3.5 h using 85% ethanol followed by oven-drying at 60°C, until the weight had stabilised and all the ethanol had evaporated.[34] The resultant sample was ethanol-insoluble and was subsequently used to determine the starch content. This was done using an enzymatic method[35,36] Measurements were performed in triplicate.

The apparent density of the plantains was determined by the ratio of the weight of a fruit to the volume of water displaced. The measurement was made three times for the quantity of plantains used on each day of the trials, always with fruit taken from the middle of the selected hand.

The full sample was crushed at the end each frying operation. Moisture content both at start time ($MC(0)$) and at time t ($MC(t)$) expressed in wet basis was determined using an approximate 5 g sample and oven-dried at 102 ± 3°C until the weight stabilised. A precision balance (SARTORIUS) accurate to 10^{-4} g was used for weighing. Measurements were performed in triplicate.

Fat content at time t ($FC(t)$), expressed in wet basis, was determined using the previously crushed and oven-dried samples. Lipid extraction was performed by hexane entrainment for 8 h at 40°C in Soxhlet devices.[37] Measurements were performed in triplicate.

The mass frying yield was calculated at times $t = 20$, 40, 60, 90, 120 and 150 s and defined by the ratio of the mass of the fried product at any moment of time ($m(t)$) to the initial mass of the product ($m(0)$) at start time $t = 0$ s. The fried products were removed from the oil, drained (1 min) and turned out onto absorbant paper. The yield was recorded and the sample stored in an airtight container.

The rate of moisture loss was calculated as the slope of the linear interpolation between the moisture content at time $t = 0$ and at time $t = 20$ s, for the first phase of the process. The rate of moisture loss for the second phase was calculated as the slope between time $t = 20$ and time $t = 40$ s. The same type of analysis was used to determine oil uptake rates in both phases.

RESULTS

Physicochemical properties such as moisture content, total sugar content, reducing sugar content, starch content and apparent density for the different varieties are presented in Table 1.

Irrespective of the reference temperature and the variety of plantain, the temperature of the bath fell by 5% during the first 30 s of frying, corresponding to a real fall of under 9°C. The temperature then rose again and the reference temperature was re-established after about 135 s of processing.

Standard deviations are not indicated on the graphs. For both moisture and fat content, the standard deviation calculated using the three kinetics curves for the replications of the experiments were under 5.2 g kg^{-1} (wb) for all varieties. The trials were thus considered to be repeatable.

Figure 1 presents the moisture content (MC) and fat content (FC) for the different varieties of plantain

Table 1. Initial composition and apparent density of different varieties of plantain. Values in brackets are standard deviations

Varieties (*Musa*)	*Moisture content* $MC(0)$ (g kg^{-1} wb)	*Total sugars* $C_{tot.sug}(0)$ (g kg^{-1} dm)	*Reducing sugars* $C_{red.sug}(0)$ g kg^{-1} dm)	*Starch content* $C_{starch}(0)$ (g kg^{-1} dm)	*Apparent density* $d_{app}(0)$ (kg m^{-3})
Dominico Hartón	585.7 ± (5.0)	7.3 ± (1.1)	1.2 ± (0.40)	851.1 ± 6.8)	980 ± (30)
Bouroukou	627.3 ± (4.7)	10.4 ± (1.0)	1.8 ± 0.85)	865.6 ± 5.8)	1040 ± (10)
Bluggoe	640.0 ± (5.2)	7.2 ± (0.5)	4.9 ± (0.75)	805.6 ± (2.6)	950 ± (30)
FHIA 21	641.0 ± (4.9)	7.1 ± (1.2)	3.4 ± (1.21)	830.0 ± (5.3)	990 ± (10)

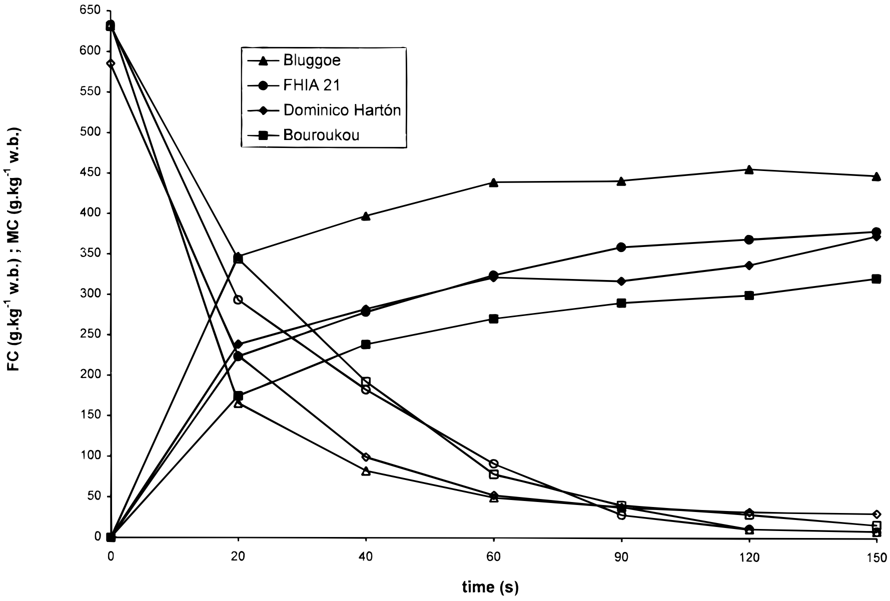

Figure 1. Frying of plantain slices ($e(0) = 2 \times 10^{-3}$ m): changes in moisture content (MC) and fat content (FC) values over time, for different varieties, at $T = 185°C$. Solid symbol, (FC); outline symbol, (MC).

during frying at a temperature of 185°C. The overall behaviour can be described in two phases. An initial phase between 0 and 20 s, during which there is rapid moisture loss and considerable fat uptake. During this phase, the rates of moisture loss ranged from 14.3 g kg^{-1} s^{-1} (wb) for Bouroukou to 23.5 g kg^{-1} s^{-1} (wb) for Bluggoe. The oil uptake rates ranged from 8.9 g kg^{-1} s^{-1} (wb) for Bouroukou to 17.4 g kg^{-1} s^{-1} (wb) for Bluggoe.

In the second phase, starting at 20 s, exchanges slowed down markedly. The rate of moisture loss dropped to 4.1 g kg^{-1} s^{-1} (wb) for Bluggoe and to 7.6 g kg^{-1} s^{-1} (wb) for Bouroukou. The same behaviour was noted in the oil uptake rate, which fell to between 2.2 and 3.1 g kg^{-1} s^{-1} (wb) for all varieties.

When the moisture content of the product reached 40 g kg^{-1} (wb), ie after about 90 s of processing, there was considerable variation in fat content between varieties. It ranged from 290 g kg^{-1} (wb) for Bouroukou to 441 g kg^{-1} (wb) for Bluggoe.

Figure 2 presents the effect of the different temperatures on moisture content (MC) and fat content (FC) during the frying of Dominico Hartón plantains. The curves have the same overall shape as in Fig. 1. The frying time needed to achieve a moisture content of under 50 g kg^{-1} (wb) was 150 s at 145°C, whereas it was only 90 s at 165°C. Processing time can thus be shortened considerably by increasing the temperature from 145 to 165°C. The temperature effect on moisture content is less noticeable when one moves from 165 to 185°C. Figure 2 also shows that temperature had a less noticeable effect on the fat content (FC) than on the moisture content (MC) of Dominico Hartón during frying. Table 2 shows the effect of temperature increase on the variation in moisture content (ΔMC) for the different varieties.

Table 2 shows that the temperature increase from 165 to 185°C had little effect on moisture content, whatever the variety. The temperature increase from 145 to 165°C, on the other hand, reduced moisture

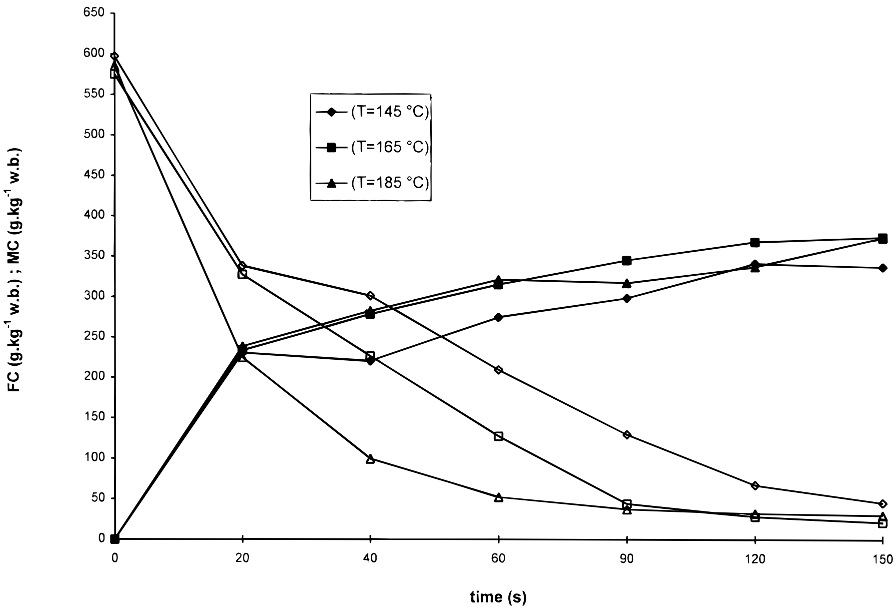

Figure 2. Frying of plantain slices ($e(0) = 2 \times 10^{-3}$ m): changes in moisture content (MC) and fat content (FC) values for the Dominico Hartón variety at three temperatures. Solid symbol, (FC); outline symbol, (MC).

Table 2. Variation in moisture content (ΔMC) for two ranges of increase in reference temperature for the different varieties (treatment time 120 s)

Varieties (*Musa*)	ΔMC ($g\,kg^{-1}$ wb) 145 to 165°C	ΔMC ($g\,kg^{-1}$ wb) 165 to 185°C
Dominico Hartón	−38.2	+4.0
Bouroukou	−63.2	−23.6
Bluggoe	−33.3	−1.1
FHIA 21	−73.9	−22.2

content considerably (by between 33.3 and 73.9 points).

Figures 3(a), (b) and (c) show the effect of temperature increase on moisture loss and oil uptake at three points in time, 90, 120 and 150 s respectively. With all three frying times, the moisture content values became less widely dispersed as the oil temperature increased. For example, at 90 s (cf Fig. 3(a)) the difference between the moisture content values for the different varieties was 96 $g\,kg^{-1}$ (wb) at 145°C, 47.6 $g\,kg^{-1}$ (wb) at 165°C and 11.9 $g\,kg^{-1}$ (wb) at 185°C.

With regard to variations in oil content, the order of the varieties always remains the same: Bluggoe, FHIA 21, Dominico Hartón and Bouroukou in descending order of oil content values. This is true for all the temperatures and processing times considered. With all varieties, a moisture content of about 40 $g\,kg^{-1}$ (wb) is guaranteed after 120 s (cf Fig. 3(b)) at temperatures of 165 and 185°C. At 145°C, on the other hand, a moisture content of 40 $g\,kg^{-1}$ (wb) was only reached after 150 s and this for only two varieties, the other two varieties still having a moisture content of about 100 $g\,kg^{-1}$ (wb) Temperature had a particularly noticeable effect on the moisture content of all varieties between 145 and 165°C, with only a slight one between 165 and 185°C. Temperature had only a minor effect on fat content, whatever the processing time. In other words, the trends observed for Dominico Hartón in Fig. 1 are found with all the varieties.

Figure 4 presents the mass yield of Dominico Hartón plantains as a function of time during frying at different temperatures. In general terms, mass yield falls as frying time increases, converging on a value of 0.5. Temperature has a more noticeable effect on mass yield with frying times of under 90 s than with long frying times. The mass yield of any variety is highest at 145°C.

Figure 5 presents the fat content values obtained at 120 s and 165°C, as a function of the initial starch content ($C_{starch}(0)$). A time of 120 s was chosen because it corresponds to the frying time needed to produce the required final moisture content of about 40 $g\,kg^{-1}$ wb. The exact moisture content values at 120 s and 165°C are also shown on the graph. It can

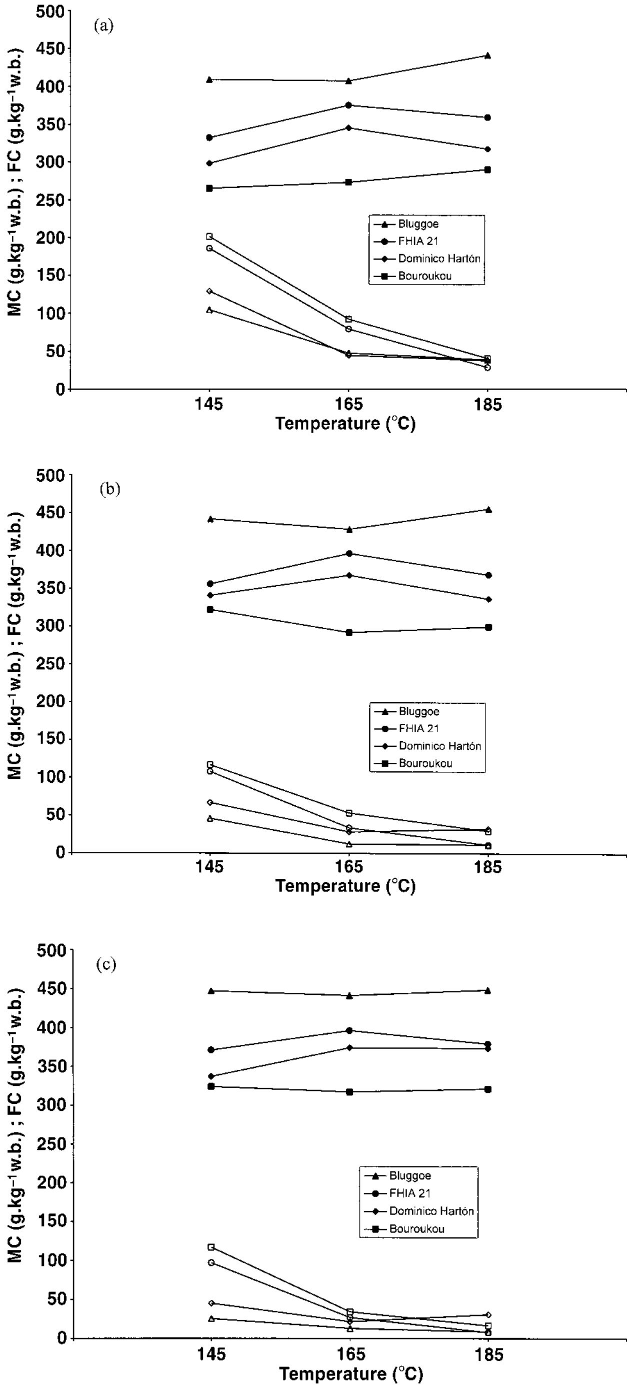

Figure 3. Frying of plantain slices ($e(0) = 2 \times 10^{-3}$ m): changes as a function of temperature, moisture content (MC) and fat content (FC) values obtained at different temperatures for different varieties. Solid symbol, (FC); outline symbol, (MC). (a) $t = 90$ s; (b) $t = 120$ s; (c) $t = 150$ s.

be seen that, for the same moisture content of about 40 $g\,kg^{-1}$ wb, the fat content falls as the initial starch content ($C_{starch}(0)$) increases. The same type of analysis at a temperature of 185°C shows the same type of behaviour.

Figure 6 presents the fat content values obtained at 120 s and 185°C, as a function of the initial total sugar content $C_{tot.sug}(0)$. As with Fig. 5, a frying time of 120 s was chosen to produce a final moisture content of about 40 $g\,kg^{-1}$ wb. The fat content is similar (about 300 $g\,kg^{-1}$ wb) for two varieties

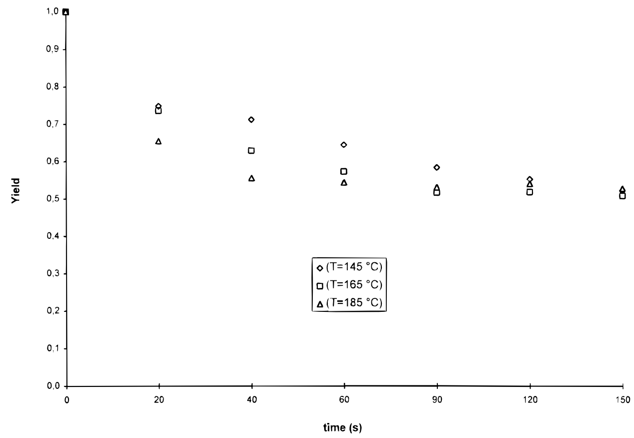

Figure 4. Frying of plantain slices ($e(0) = 2 \times 10^{-3}$ m): changes of mass yield over time, for the Dominico Hartón variety at different temperatures.

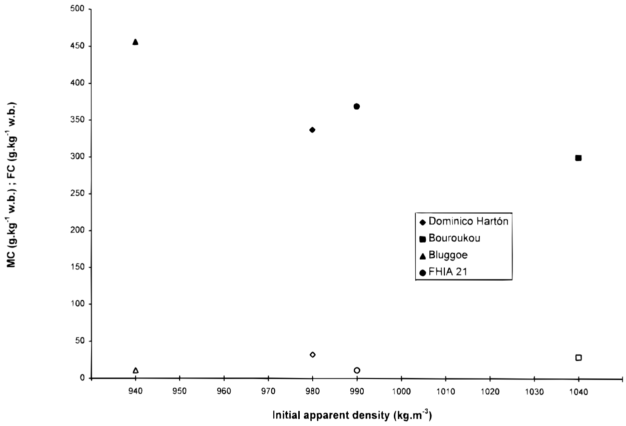

Figure 7. Frying of plantain slices ($e(0) = 2 \times 10^{-3}$ m): changes in moisture content (MC) and fat content (FC) values obtained at $t = 120$ s and $T = 185$°C, as a function of initial apparent density ($d_{app}(0)$). Solid symbol, (FC); Outline symbol, (MC).

(Dominico Hartón and Bouroukou) with very different initial total sugar contents.

Figure 7 similarly presents the fat content values obtained at 120 s and 185°C, as a function of the apparent density ($d_{app}(0)$). The time of 120 s chosen corresponds to the frying time needed to produce the required final moisture content of about 40 g kg^{-1} wb. The exact moisture content values at 120 s and 185°C are also shown on the graph. It can be seen that the fat content falls as the apparent density increases. This also occurs at the other temperatures.

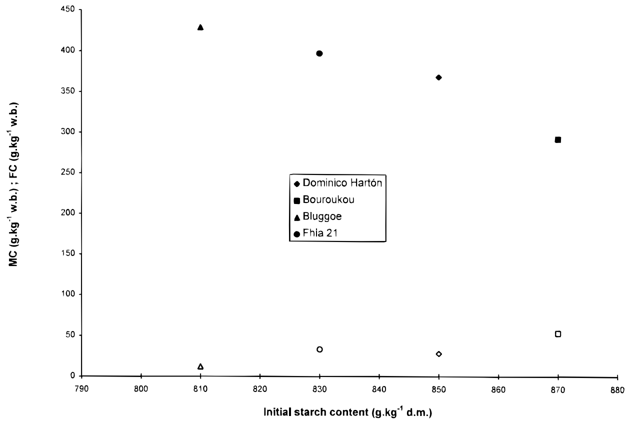

Figure 5. Frying of plantain slices ($e(0) = 2 \times 10^{-3}$ m): changes in moisture content (MC) and fat content (FC) values obtained at $t = 120$ s and $T = 165$°C, as a function of initial starch content ($C_{starch}(0)$). Solid symbol, (FC); outline symbol, (MC).

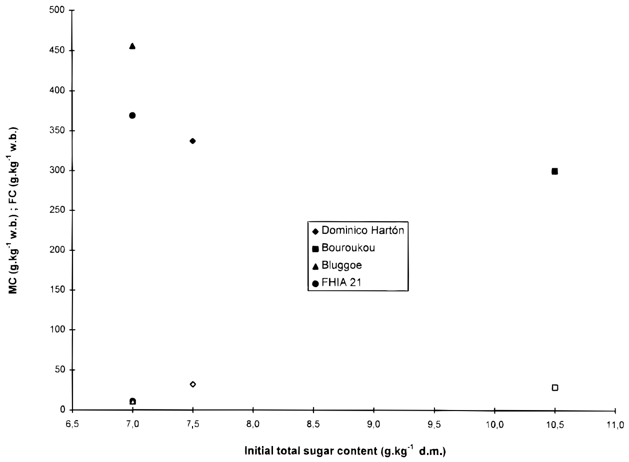

Figure 6. Frying of plantain slices ($e(0) = 2 \times 10^{-3}$ m): changes in moisture content (MC) and fat content (FC) values obtained at $t = 120$ s and $T = 185$°C, as a function of initial total sugar content ($C_{tot.sug}(0)$). Solid symbol,(FC); outline symbol, (MC).

DISCUSSION

There are many different varieties of plantain in the world. The composition of each variety changes during ripening. The initial moisture content values presented in Table 1 for the varieties tested in Colombia are similar to those reported by Eggleston *et al* (1991)[38] for African varieties: 616 g kg^{-1} (wb) for the plantain varieties Obino Lewai and Abgabga, 715 and 616 g kg^{-1} (wb), respectively, for the cooking banana varieties Fougamou and Ihitisim, and 661 and 647 g kg^{-1} (wb), respectively, for the hybrid varieties 548/4 and 548/9.

On the other hand, the starch content values presented by Eggleston *et al* (1991)[38] are slightly lower than those presented in Table 1. They report values of: 651 and 679 g kg^{-1}, respectively, for the plantain varieties Obino Lewai and Abgabga; 792 and 602 g kg^{-1}, respectively, for the cooking banana varieties Fougamou and Ihitisim; and 624 and 589 g kg^{-1}, respectively, for the hybrid varieties 548/4 and 548/9. As far as initial total sugar content is concerned, they report values higher than our results, between 21 g kg^{-1} and 121 g kg^{-1}. This discrepancy might be explained by a difference in maturity and/or by the methods of analysis used, but the authors give no details on these two points.

According to Gamble *et al*,[8] agitation of the oil bath ensures good contact between the product and the oil. In the present study we used an agitation system with a speed of rotation of 18.8 rad s^{-1}, considerably faster than that of 3.1 rad s^{-1} used by

Gamble *et al* (1987), and were therefore able to achieve homogeneity of processing and repeatable results.

Overall, our results agree with the literature in terms of both the moisture content values and oil content values achieved and the effect of temperature on transfers. Kutty *et al*[22] worked with one plantain variety (Nendran triploid AAB) and used temperatures between 150 and 195°C to prepare 2×10^{-3} m thick chips with a final moisture content of 25 g kg^{-1} (wb) and a final oil content of 310 g kg^{-1} (wb) for processing times of 135 s. Soriano *et al*[17] used temperatures between 150 and 175°C and frying times of 180 or 240 s. They used one variety of cooking plantain (Saba triploid BBB) cut into between 1.6 and 8.5×10^{-3} m thick slices. The chips obtained had a final moisture content of between 13 and 17 g kg^{-1} (wb), and a final oil content of between 323 and 401 g kg^{-1} (wb). It should be noted, however, that some authors report much longer processing times, eg 600 s for slice thickness and temperature conditions similar to those used in our experiments[20] or much lower fat content values, under 175 g kg^{-1} wb.[3,20] The longer processing time can be explained by the fact that the authors did not use an appropriate agitation system. The low fat content values are more difficult to interpret, in the absence of information on the state of maturity of the raw material and the initial starch content.

As far as the effect of temperature on transfers is concerned, the temperature increase from 145 to 165°C shortened processing time considerably, whereas the effect of temperature on processing time was slight between 165 and 185°C. This result agrees with the work of Gamble *et al*[8] and Mittelman *et al*[39] on potatoes. Gamble *et al*[8] show that oil content is independent of frying temperature, which also agrees with our results.

On the other hand, our results show that oil uptake is determined by the variety of plantain used, with the oil content values obtained varying according to variety, irrespective of processing time or temperature. Oil uptake in the case of plantain does not appear to be correlated to the raw material water content as it was previously described for potato chips production[40,41] and cassava chips.[42] Nevertheless, a positive correlation between the weight of oil uptake and the weight of water removed was observed as reported by Pinthus *et al*.[43] Oil uptake appears to be influenced by apparent density according to Gamble and Rice[41] and starch content, with oil content falling as the starch content and apparent density increase. This is a new finding of our study and differs from the studies on plantain chips reported by Onyejegbu and Olorunda.[3] The latter report similar oil content values for the three varieties tested (about 150 g kg^{-1}). We should emphasise that variety has only a slight effect on moisture content for the processing times we were interested in. The kinetics of moisture loss for the different varieties vary less once the moisture content falls to 200 g kg^{-1} and below.

Clearly the reasons for these between-variety differences in oil uptake behaviour cannot be interpreted in depth within the context of the present study. This result might be explained by an indirect effect associated with the rheological behaviour of the product, the firmness of which increases as the starch content increases.[44]

Oil uptake is in particular associated with the formation of pores and crusts.[45,46] The formation of this porous structure clearly depends on the composition and density of the material, and in particular on the behaviour of the starch during frying. The formation of the porous structure is also affected by various cooking-related phenomena capable of modifying the starch, gelatinisation in particular.

CONCLUSION

This work characterises the frying behaviour of four varieties of plantain for the 145–185°C temperature range.

The results obtained show that temperature and processing time have a major effect on moisture content. There is a particular advantage to be gained from working at a temperature of over 165°C, which gives short processing times (90 s at 185°C for a moisture content of about 40 g kg^{-1} wb). Oil uptake, on the other hand, appears basically to be linked to the variety used. The oil uptake values at 90 s and a temperature of 185°C range from about 280 to 440 g kg^{-1} (wb), depending on the variety. Oil content in plaintain chips is similar to this obtained in potato chips of 1.5 to 2.5 mm thickness, ie 30–50 g kg^{-1}.[47]

Our results have also enabled us to identify a new variety among the varieties tested, which might be of interest for industrial processing because of lower fat absorption during processing. It is worth noting that this particular variety, Bouroukou (triploid AAB, *Musa paradisiaca* Linneo), gives the most attractive appearance (ie a golden-yellow colour), a larger slice and a good yield after trimming.

This present work is of twofold interest. On a technological level, the results summarised above are necessary for process optimisation and control. On a scientific level, one original contribution of our work is that it establishes a relationship between the physicochemical properties of the raw material and varietal aptitude for frying. In particular, oil uptake appears to be linked to starch content and apparent density. These preliminary results need to be supplemented by a more detailed study of the oil absorption mechanisms of these porous starch-based structures.

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