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Osmotic pre-treatment effect on fat intake reduction and eating quality of deep-fried plantain

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Abstract

The relationship between compositional changes during frying and an osmotic dehydration step before frying is described, including and explanation of their effects on eating quality of plantain chips. Three solutions were used to soak plantain slices (glucose, salt (NaCl) and glucose + salt) prior to deep-frying (170 °C). The temperature, moisture and fat changes during the frying were monitored, and the quality attributes and physicochemical properties were also determined. The osmotic pre-treatments had significant effects on most parameters of plantain chips. In general, treatments decreased oil intake, moisture content, and total volume and also reduced frying time, while the colour, rancidity, crispiness and sensory evaluation increased after 5 min of frying. However, a negative effect on high temperature induced colour development was observed for some of the treatments. Rancidity induction times were significantly higher for pre-treated samples, which is probably related to lower oil content, shorter frying times and lower water content.

Keywords: Osmosis; Low-fat; Fried; Rancidity; Texture; Sensory; Snack; Crisp

1. Introduction

Deep-fried snacks are a popular product around the world, with a market which has been continuously increasing in value. In the UK, for example, crisps and snacks was approaching € 3.9×10^9 (Euros) in 2003 according to Mintel market data (Anonymous, 2003). In Africa, plantain chips (pekere) are popular consumer products (Onyejegbu & Olorunda, 1995) as are they in Latin America and the Caribbean (patacones, tojadas). The FAO agricultural production yearbook (FAO, 2004) listed 20 countries where plantain and bananas figured among the five most important products (based on 2002 export value). In Europe, dried plantain products have been imported and consumed as sweetened chips, mostly used in fruit and cereal mixtures. However, diet and weight related health problems are becoming a public health concern, in populations changing their traditional lifestyle and dietary patterns. To cite an example, McArthur, Holbert, and Peña (2003) concluded that a significant proportion of female teenagers (30–40%) in Latin American cities are attempting to loose weight, not always successfully. There is an interest to reduce the fat content in these products in the western world, with the major snack manufacturers developing healthier varieties to address the healthier eating niche market.

A large portion of the food market today consists of fried products from different materials including roots, tubers, cereals, bananas, plantain, fish and chicken, commonly as composites with coatings. Such products are obtained by deep-fat frying (Baumann & Escher, 1995; Ufheil & Escher, 1996), immersing in edible oil for a few minutes at high temperature between 130 and 190 °C at atmospheric pressure. Deep-fat frying is a complicated process which involves different parameters, where heat and mass transfer take place simultaneously (Saguy & Pinthus, 1995).

The frying process, including the oil diffusion has been studied for a range of products including potatoes (Baumann & Escher, 1995; Gamble, Rice, & Selman, 1987; Ufheil & Escher, 1996).

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Alternative methods of frying would be interesting if they resulted in reduced fat and cholesterol content, energy savings and production efficiency. Frying rate, quality and safety of the products, colour, texture, flavour and shelf life of the finished product are areas where improvements have been attempted with methods which include freezing, blanching, air-drying, high pressure, osmotic dehydration and the use of antioxidants (Cano, Deancos, Lobo, & Santos, 1997; Eshtiaghi, Stute, & Knorr, 1994; Sankat, Castaigne, & Maharaji, 1996; Warner, Neff, & Eller, 2003).

Frying methods used in Nigeria and traditional operations elsewhere are not consistent, and particularly the frying time and the oil temperature are only loosely controlled, the type of oil and storage and packaging are subject to variability and no pre-treatments are applied. Air-drying of plantain chips has been reported to yield significant differences in oil uptake and eating quality (Gupta, Shivhare, & Bawa, 2000). The application of sugar solutes in potato products, in a process involving either immersion or spraying solutions of sugars or salt (Gupta et al., 2000; Krokida, Oreopoulou, & Maroulis, 2000b, 2001a) results in the reduction of the moisture content before frying, involving solid materials infused into the product matrix and shrinking. However, the frying behaviour of green plantain, particularly in relation to pre-treatments, has not been studied in detail.

The aim of this study was to examine the relationship between frying process parameters and the solution used for osmotic dehydration before frying, and explains their effects on eating quality of plantain chips.

2. Materials and method

2.1. Experimental design

The treatment samples were prepared by subjecting plantain to solutions of either glucose, salt, salt and glucose or water (control). A benchtop scale frying process was set up to establish the pre-treatment effect on the frying process parameters by monitoring the temperature, moisture and fat changes during the frying process of treatment samples. This experiment was carried out in triplicate. Fried plantain chips changes were monitored for colour parameters, shape, volume, instrumental texture and sensory profiles. Determinations were carried out on samples from frying trials, and also on final product after storage. Statistical analysis included descriptive statistics using Microsoft Excel (V. 10.0/6789), general lineal model (GLM) with Tukey's comparisons (moisture, fat, oil temperature, texture and colour parameters against treatment, time and replicate; sensory scores and induction time against treatments and time) and balanced one-way ANOVA (treatments against time and replicate for total volume) (Eddison, 2000) and Minitab software (V. 13.32, Minitab Ltd., Coventry, UK).

2.2. Preparation of samples

Mature green plantains (*Musa Paradiasiacas* spp.) and sunflower oil were sourced from a local retailer (Tesco, Cheshunt, UK). Circular slices were obtained (thickness 2 ± 0.1 mm; diameter 3.5 ± 0.1 cm) and blanched by immersing them in a water bath that was kept at 70 °C/10 min and randomly allocated to four groups. Water was used for the control, and a ratio of 300 g solute/kg plantain and 1 kg batches of plantain slices was maintained for treatment samples. Three types of 20%(w/w) solutions of glucose, salt and the combination (1:1) of glucose and salt were used for the dehydration step.

The excess water was removed by gently blotting off with absorbent paper. The sliced plantain pieces were randomly divided into four groups for each pre-treatment including the control.

2.3. Frying process

A benchtop commercial deep-fat fryer with temperature control of +1 °C and a modified mesh wire basket with compartments was used. The fryer was filled with 2 l of oil and the sliced plantain ratio to oil was kept at 1:50 w/w, following the method used by Krokida, Oreopoulou, Maroulis, and Marinos-Kouris (2001a). The temperature of the frying oil was set at 170 °C and monitored with a type K temperature probe and datalogger at 10 s intervals (N1092, EVG with Evolution software, Comark, Stevenage, UK). For each replicate, 60 g of sample per sampling time and about 333 g of samples were used. The chips samples were sequentially removed from the oil at times 0, 1, 2, 5 and 10 min, drained and transferred onto a mesh tray placed on absorbent paper. After each frying test, the oil level was checked and topped up if needed; oil batches were not kept hot for more than 2 h. The frying experiment was carried out in triplicate and the values reported as the average per sampling time.

2.4. Determination of changes on plantain chips

Moisture and fat content were determined in triplicate and calculated following standard methods (James, 1995). Moisture was determined from 10 g samples by weight difference after drying in a vacuum oven (70 °C, 6400 mbp) for 18 h. Fat content was determined by the Soxhlet/Soxtex extractor method by continuous extraction with petroleum ether from 2 g of sample (James, 1995).

Total volume determination from 1.91 g plantain chips approximately was weighed and immersed and allowed to settle in a graduated 10 ml measuring cylinder with 6 ml of *n*-heptane. The total volume was then determined by the difference of the displacement with accuracy of ±0.1 ml, and reported as mean values of triplicate determinations.

2.5. Oxidative rancidity of plantain chips

Oxidative stability of the samples after 30 days storage was measured in duplicate using an accelerated method on oil at 120 °C with a rancidity oxidation conductivity meter (Rancimat 679, Metrohm Ltd., Herisau, Switzerland). Samples were ground with mortar and pestle and 0.5 g were dispensed into the equipment tubes (no sample in control tube) containing 2.75 g of refined pure sunflower oil (3.25 g of in control tube). The measuring vessels were filled with 70 ml of distilled water. After completion of the oxidation process by air circulation, the induction time was determined from the conductivity plots.

2.6. Colour determination

The colour of plantain chips samples was measured by reflectance using a colorimeter was used (CR200, C illuminant, 0° viewing angle (2° observing angle), 8 mm aperture, Minolta, Japan). Each sample was measured in three different locations to determine L^*, a^* and b^* values where L^* (lightness) was the quantity of reflected light and chromatic co-ordinates, a^* (redness) and b^* (yellowness). The results were expressed in the $L^*a^*b^*$ calibrated colorimeter system according to the 1986 CIE standards (MacDougall, 2000).

2.7. Texture analysis

The textural properties of plantain chips were determined instrumentally using a texture analyser (Stable Micro Systems Ltd., UK) fitted with a 5 kg load cell and a three-point bending rig (HDP/3PD) with a 30 mm gap between the two supporting blades and the upper blade at an equidistant position above the centre to gently to bend or fracture the sample. The texture measurements were conducted in triplicate samples with three chips each from each sample for times 2, 5 and 10 min, at room temperature 20 ± 2 °C. Overall peak force forces were the mean values of the three determinations.

2.8. Sensory evaluation

A simplified quantitative descriptive analysis method adapted following recommendations by Carpenter, Lyon, and Hasdell (2000) to determine eating quality, and specific sensory attributes of the plantain chips including darkness, yellowness, appearance, stickiness, crispness, oiliness, flavour, saltiness, sweetness and overall acceptability. A 10 member panel with experience in sensory evaluation was selected after screening, and briefed but not trained. Fried plantain was tested 24 h after production, presenting eight samples of four slices (12 ± 2 g) to the panel in random order to be scored for intensity using an ordinal scale (Resurrection, 1998) and a nine-point hedonic scale from 1 (dislike extremely) to 9 (like extremely). The procedure and analysis of results were carried out following standard methods (ISO 6564-1985, 1986).

3. Results and discussions

3.1. Moisture, solids and volume

As expected, the moisture loss and oil uptake during the frying time show a similar trend. The final moisture of the control samples (64.5%) was significantly higher that of those pre-treated with glucose (58.1%), salt, and salt and glucose (both 52.9%). This showed that the effect of osmotic dehydration pre-treatment on the sliced plantain has drastically reduced the moisture content of the samples especially for salt and glucose and salt treatments, thereby shrinking the samples as well as certain solid infused into the product matrix (Krokida, Oreopoulou, & Maroulis, 2000a, 2000b).

Total volume determination is slightly affected by the osmotic pre-treatment. It is clear that the result as shown in Fig. 3, revealed that the total volume tends to increase with the time of frying (time 0 = 1.6 and time 10 = 2.18 for control; time 0 = 1.39 and time 10 = 1.92 for glucose and salt). The mean values indicate that as more oil is absorbed by the sample in respect to an increased in frying time, more volume space is created regardless of the treatment. In particular, the initial total volume of pre-treated samples tended to decrease. Fig. 3 shows that the control sample has the highest values, followed by the glucose and salt combination and glucose, respectively, while salt

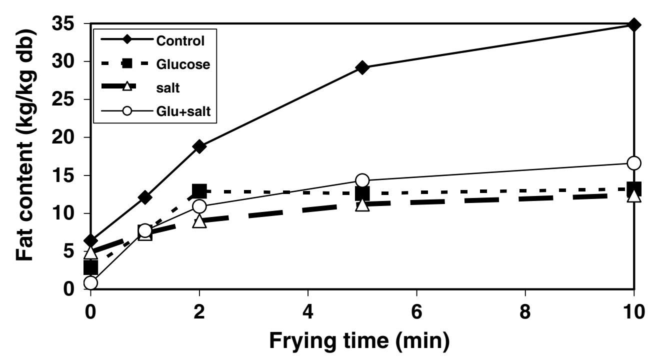

Fig. 1. Oil uptake of plantain chips pre-treated with osmotic solutions.

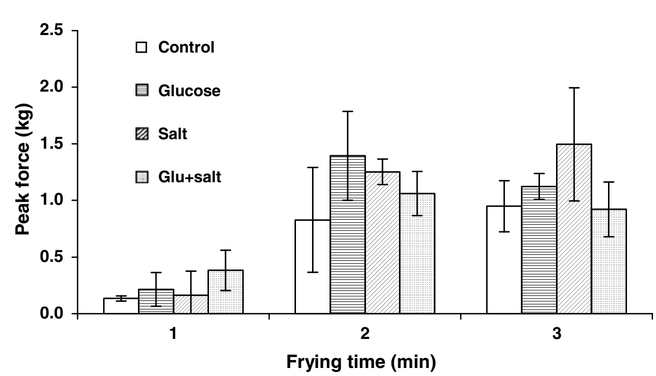

Fig. 2. Texture (mean ± standard deviation) of plantain chips pre-treated with different solutions, as it changed over the frying period.

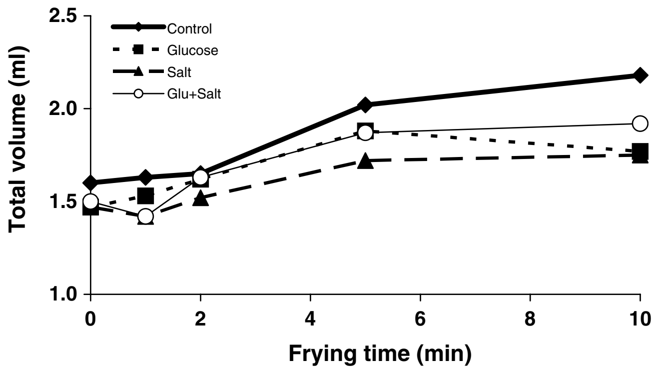

Fig. 3. Effect of osmotic pre-treatment and frying time on total volume of fried plantain chips.

samples had the lowest mean values, confirming that osmotic pre-treatment has an effect on the total volume of plantain chips.

Balanced ANOVA analysis, plotting treatment against time and replicates revealed that treatments and control are significant different with time ($p < 0.001$ for control, salt, salt + glucose; $p \leqslant 0.001$ for glucose), while treatment against replicates showed no significant differences except for glucose + salt ($p = 0.04$). This implied that osmotic pre-treatment on fried plantain chips with regard to time of frying, is significantly influences the total volume of the product.

3.2. Fat content

The results of parameter estimation for the oil absorbed in plantain chips during frying are similar to moisture content but data was in the opposite direction. Meaning that as the time of frying increases, more fat is absorbed in the samples. Percentage mean scores of oil content are shown in Fig. 1.

Osmotic pre-treatment decreases the oil content of plantain chips during frying in varying proportion. The result showed that as frying time increases, the oil content infused into the samples increases irrespective of oil temperature and treatment, but in varying proportion. The control samples had the highest percentage of fat content in all the frying time range. The lowest fat content values are given by the pre-treatment with NaCl solution, followed by Glucose solution, while glucose + salt were next to the control samples. From Fig. 1, the line graph shows closeness of the samples treated with pre-treatments when compared to the control sample, indicating that the osmotic pre-treatment had reduced the oil uptake in those samples where osmotic dehydration has taken place (Guillaumin, 1988) which is in compliance with previous results on potatoes by Krokida et al. (2001a, 2001b) and Gamble et al. (1987). Using the GLM with Tukey's test at 95% confidence, and a plot of fat versus treatment and time and replicate, the results showed that there were highly significant effects due to treatments ($F = 20.36$; d.f. = 3.50; $p < 0.001$) and time ($F = 22.28$; d.f. = 4.50; $p \leqslant 0.001$) while among replicates no significant difference ($p = 0.858$) was found. Subsequent Tukey's tests showed that treatments showed highly significant differences while there are no significant for control samples.

The use in osmotic pre-treatment affected the final oil content intake in the product. This is as a result of reduction in the initial moisture content of the product and partially gelatinising the starch molecules in the samples after frying (Moreira & Palau, 1995). Other factors that may be responsible for the reduction of oil content intake in those samples treated with osmotic dehydration including infusion of solid material into the sample matrix when the moisture content is reduced as discussed by Krokida et al. (2001a). Looking at the result from frying time point of view the result obtained showed that as the frying time increased from 1 to 10 min, the fat content also increases.

3.3. Oil temperature

The fryer was set at 170 °C, which was the temperature at the beginning of the process ($t = 0$) but changed as the process progressed ($t = 10$ min). As expected, the oil temperature dropped immediately when a batch of chips was immersed, due to the energy transfer from the cooler chips and evaporating water, then it started to rise gradually until it was slightly above 170 °C in about 2 min. As shown in Fig. 4, the dropping of the temperature in the initial stages of frying may be due to initial high moisture content of the plantain, which reduces the temperature of the oil to 133.5 °C (LSM) at 2 min. This is consistent with the model proposed by Krokida et al. (2000b) where moisture content and oil temperature are inversely related. The gradual increase of the oil temperature above the temperature setting may be attributed to the treatments as more moisture was withdrawn from the samples before frying, having an additional effect on the size. Fig. 4 also revealed that the control sample had the lowest oil temperature, followed by glucose treated samples and salt solution, while the oil temperature of samples treated with glucose + salt solution

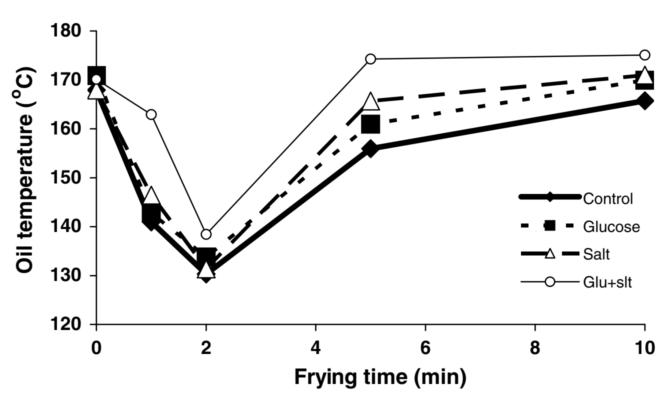

Fig. 4. Influence of osmotic pre-treatment and frying time on oil temperature of fried plantain chips.

recorded the highest, slightly above the temperature 170.4 °C at 10 min (LSM) from GLM analysis.

In the GLM analysis with oil temperature versus treatment, time and replicate, the plot revealed that pre-treatments samples are significantly different ($F = 4.14$; d.f. = 3.38; $p = 0.012$), time ($F = 32.71$; d.f. = 4.38; $p < 0.001$) had a highly significant effect, as id replicates ($F = 8.45$; d.f. = 2.38; $p \leqslant 0.001$). Subsequent Tukey's test showed that treatment 2 (glucose), 3 (salt) were not statistically significant with the control while treatment 4 (glucose + salt) were significant ($p = 0.008$). Comparison of the treatments with salt against the glucose treatment revealed that their effect is not significant.

3.4. Texture

The mean score of texture analyser results after 1 week of fried with corresponding standard deviations are shown in Fig. 2.

Texture is one of the main sensory quality attributes affecting food acceptance. Plantain chips' texture is widely recognised as one of the most important parameters to determine the quality and storageability of the chips in tropical regions where its production is on a large scale. (Ogazi, 1985; Onyejegbu & Olorunda, 1995). In this study, the peak force was the major area of discussion. Plantain chips exhibit fracturability which possesses a high degree of hardness and a low degree of adhesiveness which is measured as the horizontal force with which a food moves away from the point where the vertical force is applied and the point with which the sample breaks. The three-point bend rig settings and replicates on the texture determinations, helped to eliminate point stresses and improve the reproducibility of the test (Luyten, Van vliet, & Walstra, 1992).

As shown in Fig. 2, the lowest peak force (texture) values were recorded for the control samples, followed by glucose + salt, which were very close for which the time had no effect. The difference between the control sample and treatment results may be due to the inherent non-homogeneous texture and structure of plantain chips treated with pre-treatment because the structural shapes and size become imbalanced after frying. An additional reason may be due to different times of frying because those fried for 5 and 10 min, recorded higher numbers of peak force than those in 2 min. GLM analysis (texture versus treatment, time and replicate) revealed that the treatments are not significantly different, but time is highly significant ($F = 22.92$; d.f. = 2.22; $p < 0.001$). Tukey's tests revealed that for treatments 2, 3 and 5 the texture of samples is not significantly different to that of the control. Similarly, treatment 3 and 4 are not significantly linked with treatment 2 (glucose).

3.5. Colour

Mean scores of the $L^*a^*b^*$ parameters are indicated in Fig. 5 showing the variation of colour in each pre-treatment of chip samples. The colour of food plays an important role in how consumer perceives a product; therefore, it is important to be able to assess the colour.

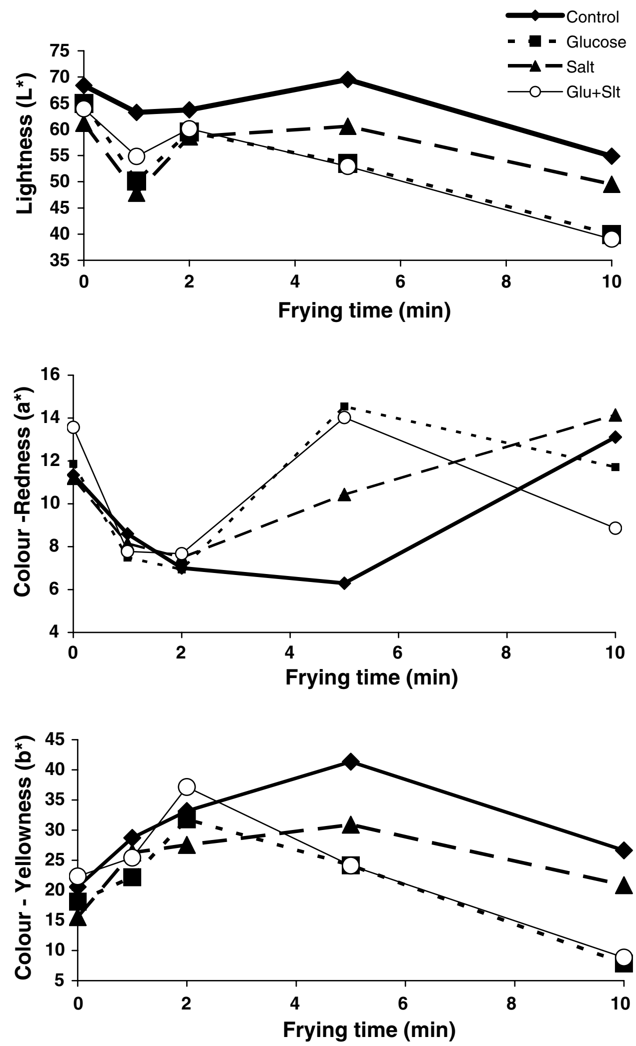

Fig. 5. Effect of osmotic pre-treatment and frying time on the colour (L,a,b values) of fried plantain chips.

The lightness (L^*) of plantain chips decreased significantly as the frying time increased from 5 to 10 min. This trend was more intense in the samples treated with osmotic pre-treatment. This darkening may be due to high sugar content present in the treatment used, especially those treated with glucose, and glucose + salt, which would aid caramelisation in the sliced fruit. The differences in colour ($L^*a^*b^*$) within treatments was small, but the control and salt were generally different. This darkening, typically linked to Maillard reactions between sugars and amino groups may be promoted by the high sugar content, especially those samples treated with glucose, and glucose + salt, which also aid caramelisation in the sliced fruit (Krokida et al., 2001a; Onyejegbu & Olorunda, 1995). Lower water contents and reduced sample volume, would result in an increased oil temperature (Krokida et al., 2000a). The results revealed that pre-treatment have a high significant effect on lightness values ($F = 16.14$; d.f. = 3.50; $p < 0.001$), time ($F = 16.32$; d.f. = 4.50; $p < 0.001$) while the comparisons result revealed that treatments 2, 3, and 4 are significant to the control, and treatments 2, 3, and 4 are not significantly different between each other.

The redness was also affected by the process variables. In plantain, elevated a^* values linked to dark brown colours are not desirable because that would be linked to a burned unacceptable fried plantain, as pointed out by panellists. As shown in Fig. 5, the redness increased during frying. As the time of frying was extended to 5 and 10 min, the redness increased which has been linked to negative attributes in potato fried products (Krokida et al., 2000b). Fig. 5 and sensory data (Table 2) shows how glucose samples had the highest values of redness, followed closely by glucose + salt, while the control had the lowest values. The result may be due to the effect of pre-treatments and linked to longer time of frying allowing the development of Maillard reaction products. On some products (i.e. palm oil) the sample redness will be influences by oil, plant material or ingredients such as spices, but not in this case. GLM ANOVA showed that treatments did not have significant effect on the redness values, but time was highly significant ($F = 8.93$; d.f. = 4.50; $p < 0.001$). The yellowness (b^* values) are the consumer focus on plantain chips. In general, higher b^* values are linked to yellow plantain products which are desirable. The process variables (thickness level, frying time and treatment level) affect the yellowness in the same manner that they affect the lightness (L^*). Fig. 5 shows that the control sample has the highest yellow colour, followed by salt treated samples, while glucose + salt and glucose recorded the least yellow colour. The variation in yellowness between the control and the treated samples may be due to the treatment used (glucose and salt) because they are not effective in preventing enzymatic browning that may be responsible for the darkening of the colour. Treatments had a very significant effect on yellowness (b^*) of plantain chips ($F = 5.36$; d.f = 3.50; $p = 0.003$). Frying time was highly significant ($F = 14.92$; d.f. = 4.50; $p < 0.001$). Both glucose treatments had a significant effect ($p = 0.002$ and 0.026, respectively) on colour when Tukey's comparisons were performed against the control while salt pre-treatment had no significant effect on colour.

3.6. Oxidative rancidity

This experiment was designed to determine the stability of plantain chips, when the oxidation products are diffused from the stored product into the sunflower oil used as the carrying medium. Before the formal experiment the oxidative stability of sunflower oil and plantain chips samples from Nigeria were determined. The conductivity versus time curve was plotted and the sudden increase in the slope of these curves was considered to mark the onset of the oxidation process, while the time elapsed since the start of the test is the induction time (Makus & Peter, 1986; Warner et al., 2003). The results showed that all the tested plantain chips had lower induction time when compared with the oil (sunflower), which was used as a baseline. The stability index could be determined by the induction time of the sample divided by induction time of the oil. Nigerian products from street vendors had lower stability index (results not shown). This implied that to lower stability values, the product would be more susceptible to show rancid flavour. The poor stability may be attributed to the type, quality and stability of oil (palm oil used), methods of frying, low oil change rates and cleaning between batches, overheating and low performance of packaging material and lack of pre-treatment before frying.

Table 1 compares mean induction periods of sunflower oil and oil where osmotic pre-treatment sample has been steeped. Samples G10, S10 and G + S10 had the highest induction time, which may be as a result of both the pre-treatment used, and the longer time of frying, which implied that the pre-treatment prevented the product from spoilage by rancidity at the expected time of 1.53 h in contrast to most of the plantain chips sampled from retailing points in Nigeria. Samples G5, C10 and C5 also had longer induction periods and hence longer shelf life. S5 has the lowest induction period, probably as a result of a shorter frying time which resulted in product with higher water activity, and could be linked to some oxidative reactions. Time ($p \leqslant 0.001$) and treatments had a significant effect (GLM, $F = 5.42$, d.f. = 4.19, $p = 0.008$) on rancidity development, and subsequent Tukey's comparisons of means showed that only samples treated with salt were significantly different to the control. Comparisons of glucose treatment against others revealed no significant difference among samples. Salt treated samples were not different to other in induction time (Table 1).

The findings indicated that samples treated with osmotic pre-treatment give a longer induction period than the control samples after 10 min of frying. The result clearly showed that longer time of fried plus the use of pre-treatment exhibited longer induction time.

3.7. Sensory evaluation

The mean values for sensory attributes of plantain chips at 2 min fried were compared (Table 2). The preference rat-

Table 1
Comparison of the induction periods[A] (h) of sunflower oil media with osmotic pre-treatment samples fried for 5 and 10 min

Treatment	Frying time	
	5 min	10 min
Blank (oil)[B]	2.23 ± 0.04	
Control	2.33 ± 0.04^a	2.40 ± 0.01^b
Glucose	2.52 ± 0.02^c	2.68 ± 0.04^d
Salt	2.19 ± 0.12^a	2.64 ± 0.02^d
Glucose + salt	2.26 ± 0.08^a	2.67 ± 0.02^d

[A] Means ± sd ($n = 3$); means with different subscript are significantly different.
[B] Induction time = 2.23 ± 0.04 h.

ing for yellowness and overall appearance were higher in salt than any other pre-treatments. Glucose treated samples were high in sweetness, overall acceptance, flavour and oiliness, while control samples had the least in all the attributes except stickiness. As expected, treating the plantain with osmotic pre-treatment before frying improved their appearance and other attributes desirable by consumers with short term fried. This is as a result of the pre-treatments being inactivate the enzymes responsible for browning reactions as discussed by Cano et al. (1997). However, some of this advantage may be less when fried for a longer period and at a high temperature above 170 °C. As shown in Table 2, sensory attributes of plantain chips after 5 min frying, revealed that pre-treated samples scored higher in all the attributes. Glucose treated samples were high in crispness, overall acceptance, flavour and sweetness. Salt recorded the highest in yellowness and overall appearance followed by the glucose + salt treated sample, while the control samples had the lower scores. This may be related to the faster crispiness development due to moisture removal before frying, with the consequent faster reach of the optimum moisture and oil content (Cano et al., 1997; Eshtiaghi et al., 1994). However, temperatures above 170 °C with a longer time of frying may result in quick darkening of the frying product because of the higher content of reducing sugar available to heat induced reactions when a sugar was increased with pre-treatment before frying (Toma, Leung, Augustin, & Iritani, 1986). The mean scores and standard variation values are shown (Table 2) for each attribute. The results revealed that yellowness, sweetness and overall acceptability were significantly different ($p < 0.05$) amongst pre-treatments, while time had no significant effect in yellowness and sweetness but significantly influenced overall acceptability. Subsequent Tukey's test (95% confidence) on yellowness (b^*) showed that both glucose treated samples were not significantly different to the control samples, unlike those treated with salt only. In a similar way, glucose and salt treated samples were significantly different, but the addition of did not make a difference. Tukey's test for sweetness revealed that the glucose treated samples are significantly different to the control product. A similar result was found for acceptability, which demonstrates that an osmotic pre-treatment could produce attributes in demand by consumers.

Treatments had no significant effect on other sensory parameters (darkness, overall appearance, stickiness, crispiness, oiliness, flavour and saltiness). For some attributes such as saltiness and acceptance, variability of hedonic scores was higher than for others. The panel would be expected to discriminate between the attributes of the plantain chips, but differences in acceptance due to personal preference were expected and considered to be consistent with those of a sample of consumers matching their profile. While the sensory evaluation clearly revealed that glucose treated samples were preferred, and that rancidity was a negative attribute for this panel, this is not always the case as demonstrated by an example of a traditional fried product with added rancid flavouring, to suit the market expectation in a Western European country (Sidel, 2002).

Plantain chips texture is widely recognised as one of the most important parameters to determine the quality in tropical regions where production is on a large scale. (Onyejegbu & Olorunda, 1995). As shown in Fig. 2, the lowest peak force values are those corresponding to the control samples, followed by those treated with glucose and salt, while pre-treatment with glucose and salt solutions resulted in very similar texture. Variability within treatment samples was high, probably because the structural shapes and size

Table 2
Mean scores for sensory attributes of plantain chips fried during (a) 2 min and (b) 5 min, with a balanced scale from 1 (dislike extremely) to 9 (like extremely)

Attribute	Frying time (min)	Treatments			
		Control	Glucose	Salt	Glucose + salt
Darkness	2	4.9 ± 0.99	5.0 ± 1.15	5.4 ± 2.12	4.2 ± 1.75
	5	5.6 ± 1.35	5.2 ± 1.23	4.3 ± 2.26	5.7 ± 1.06
Yellowness	2	5.6 ± 1.51	5.5 ± 1.51	7.2 ± 0.92	5.7 ± 1.06
	5	5.8 ± 1.99	4.8 ± 1.40	6.9 ± 2.02	5.4 ± 1.90
Appearance	2	5.1 ± 1.20	5.6 ± 1.26	6.4 ± 1.17	5.4 ± 1.26
	5	5.8 ± 1.55	4.9 ± 1.45	6.6 ± 1.43	5.4 ± 1.90
Stickiness	2	4.6 ± 2.27	3.4 ± 1.78	4.1 ± 1.73	3.7 ± 1.70
	5	5.0 ± 1.63	4.5 ± 1.96	4.0 ± 1.70	4.3 ± 2.00
Crispiness	2	3.3 ± 1.42	2.1 ± 0.88	2.7 ± 1.49	2.9 ± 1.37
	5	5.2 ± 1.55	7.7 ± 1.16	5.6 ± 2.46	7.0 ± 2.45
Oiliness	2	5.1 ± 1.52	4.9 ± 2.02	3.7 ± 1.70	4.1 ± 1.91
	5	5.3 ± 1.70	4.7 ± 2.41	4.5 ± 1.18	4.0 ± 1.05
Flavour	2	3.9 ± 1.73	5.4 ± 1.26	4.4 ± 2.17	5.3 ± 1.95
	5	4.9 ± 2.02	7.0 ± 1.05	4.6 ± 1.84	5.5 ± 1.27
Saltiness	2	3.2 ± 1.69	3.8 ± 2.20	4.4 ± 3.66	3.2 ± 1.69
	5	4.8 ± 1.87	4.8 ± 2.66	3.9 ± 3.18	5.7 ± 2.41
Sweetness	2	3.8 ± 2.30	6.7 ± 1.49	3.4 ± 1.84	3.7 ± 1.95
	5	4.3 ± 1.49	7.0 ± 1.41	3.9 ± 1.91	5.3 ± 1.70
Acceptability	2	3.9 ± 1.85	5.6 ± 1.71	3.2 ± 2.20	3.9 ± 1.79
	5	5.4 ± 1.78	7.4 ± 1.07	3.9 ± 2.02	5.0 ± 1.63

become imbalanced after frying. Different times of frying clearly influenced the texture because those fried for 5 and 10 min, recorded higher numbers of peak force than those in 2 min. From GLM, comparisons of the texture versus treatment and time, no significant links were detected.

The results revealed that osmotic pre-treatment had a significant effect on moisture content, fat intake, oil temperature, texture, colour, oxidative stability, total volume and the sensory attributes of plantain chips.

The preference rating for yellowness and overall appearance were higher in salt treated samples than any other samples. Glucose treated samples were high in sweetness, overall acceptance, flavour and oiliness, while control samples had the lower scores in all the attributes except stickiness. As expected, applying an osmotic pre-treatment to plantain before frying improved the appearance and other attributes desirable by consumers in fast fried products. The sensory panel did not detect significant differences ($p > 0.05$) among treatments and control in the other sensory parameters (darkness, overall appearance, stickiness, crispiness, oiliness and flavour). The treatments and their corresponding differences in moisture content resulted in different rates of frying, and clearly the intensity of the sensory attributes and corresponding acceptance were linked to the frying time. It is therefore important to adjust the frying time to obtain optimum quality attributes when osmotic treatments are applied. It could be considered that further advantages of pre-treatment could be a reduced frying time and therefore reduce the temperature drop on the oil (results not shown), which would improve energy use, reduce oil overheating and probably contribute to uniform colour, if the pores are water content of the surface is uniform due to the pre-treatment. Additional benefits include the reduction of loose starch and lowered stickiness of pieces, reducing the formation of clusters during the frying process.

4. Conclusions

The application of osmotic pre-treatments affected the quality parameters examined in plantain chips. The rates of mass transfer (moisture loss and oil intake) during the frying of plantain chips increased as a result of the osmotic pre-treatment. Also, darkening (browning reactions) occurred at higher oil temperatures when the frying period was extended over 5 min. Pre-treatment samples have the most acceptable colour (golden yellow) than the control after 5 min of frying, while at 10 min the control sample had the best colour.

In general, the osmotic dehydration pre-treatments decreased the oil intake, moisture content, total volume and also reduced the frying time, when compared with the control, while the colour parameters, rancidity, texture peak force and sensory evaluation increased after 5 min of frying. However, a negative effect was linked to high temperatures induced colour development as observed for some of the treatments. Rancidity induction times were significantly higher for pre-treated samples, consistent with the registered lower oil content, shorter frying times and lower water content. The use of the osmotic pre-treatment with an antioxidant or oxygen exclusion system is recommended for a longer shelf life of the product. Further research is needed in the area of packaging, the combination of pre-treatments with antioxidants and rancidity development in relation to the shelf life and acceptability of this product.

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References

Anonymous (2003). Crisps and Snacks UK. Market Report, June 2003. London: Mintel International Ltd.

Baumann, B., & Escher, F. (1995). Mass and heat transfer during deep-fat frying of potato slices. I. Rate of drying and oil uptake. *Lebensmittel Wiss Technologie, 28*, 395–403.

ISO 6564-1985 (1986). Part 4: Flavour profile methods. In *Methods for sensory analysis of food (BS 5929-4)*, London: British Standards Institution.

Cano, P. C., Deancos, B., Lobo, M. G., & Santos, M. (1997). Improvement of frozen banana (*Musa cavendishii*, cv *enana*) colour by blanching relationship between browning, phenols and polyphenol oxidase and peroxidase activities. *Zeitschrift fur Lebensmittel Untersuchung und Forschung A – Food Research and Technology, 204*, 60–65.

Carpenter, R., Lyon, D., & Hasdell, T. A. (2000). *Guidelines for sensory analysis in food product development and quality control*. Gaithersburg, MD: Aspen Publishers.

Eddison, J. (2000). *Quantitative investigation in the biosciences using Minitab*™. London: Chapman & Hall/CRC.

Eshtiaghi, M. N., Stute, R., & Knorr, D. (1994). High-pressure and freezing pretreatment effects on drying, rehydration, texture and colour of green beans, carrots and potatoes. *Journal of Food Science, 59*, 1168–1170.

FAO (2004). *FAO Statistical Yearbook 2004*. Rome: Statistics Division, Food and Agriculture Organisation.

Gamble, M. H., Rice, P., & Selman, J. D. (1987). Relationship between oil uptake and moisture loss during frying of potato slices from cv. *record* UK tubers. *International Journal of Food Science and Technology, 22*, 233–241.

Guillaumin, R. (1988). Kinetics of fat penetration in food. In E. Bender & I. D. Morton (Eds.), *Frying of food* (pp. 457–465). Chichester, England: VCH.

Gupta, P., Shivhare, U. S., & Bawa, A. S. (2000). Studies on frying kinetics and quality of french fries. *Drying Technology, 1–2*, 311–321.

James, C. S. (1995). *Analytical chemistry of foods*. Glasgow: Blackie Academic and Professional.

Krokida, M. K., Oreopoulou, V., & Maroulis, Z. B. (2000a). Effect of frying conditions on shrinkage and porosity of fried potatoes. *Journal of Food Engineering, 43*, 147–154.

Krokida, M. K., Oreopoulou, V., & Maroulis, Z. B. (2000b). Water loss and oil uptake as a function of frying time. *Journal of Food Engineering, 44*, 39–46.

Krokida, M. K., Oreopoulou, V., Maroulis, Z. B., & Marinos-Kouris, D. (2001a). Effect of osmotic dehydration pretreatment on quality of French fries. *Journal of Food Engineering, 49*, 339–345.

Krokida, M. K., Oreopoulou, V., Maroulis, Z. B., & Marinos-Kouris, D. (2001b). Effect of pre-drying on quality of French fries. *Journal of Food Engineering, 49*, 347–354.

Luyten, H., Van vliet, T., & Walstra, P. (1992). Comparison of various methods to evaluate fracture phenomena in food materials. *Journal of Texture Studies, 23*, 245–266.

MacDougall, D. B. (2000). Colour measurement of food principles and practice. In D. B. MacDougal (Ed.), *Colour in food-improving quality* (pp. 33–63). Cambridge: Woodhead Publishing.

Makus, W. L., & Peter, A. B. (1986). Determination of the oxidative stability of fats and oil: comparison between the active oxygen method and the rancimat method. *Journal of the Association of Analytical Chemists, 63*, 792–795.

McArthur, L. H., Holbert, D., & Peña, M. (2003). Prevalence of overweight among adolescents from six Latin American cities: a multivariable analysis. *Nutrition Research, 23*, 1391–1402.

Moreira, R. G., & Palau, J. E. (1995). Thermal and physical properties of tortilla chips as a function of frying time. *Journal of Food Processing and Preservation, 19*, 175–189.

Ogazi, P. O. (1985). Production of plantain chips in Nigeria. In *Proceedings of the 3rd meeting of the International Association for Research on Plantain and Banana* (pp. 160–161). Abidjan, Ivory Coast: IARPB.

Onyejegbu, C. A., & Olorunda, A. O. (1995). Effects of raw materials, processing conditions and packaging on the quality of plantain chips. *Journal of the Science of Food and Agriculture, 68*, 279–283.

Resurrection, A. V. A. (1998). *Consumer sensory testing for product development*. Gaithersburg, MD: Aspen Publishers.

Sankat, C. K., Castaigne, F., & Maharaji, R. (1996). The air drying behaviour of fresh and osmotically dehydrated banana slices. *International Journal of Food Science and Technology, 31*, 123–135.

Saguy, I. S., & Pinthus, E. J. (1995). Oil uptake during deep-fat frying: factors and mechanism. *Food Technology, 49*(4), 142–145.

Sidel, C. (2002). Some lesson vignettes from focus groups and other market research. In C. Sidel (Ed.), *Food product development based on experience*. London: Blackwell Publishers/IFT.

Toma, R. B., Leung, H. K., Augustin, J., & Iritani, W. M. (1986). Quality of French fried potatoes as affected by surface freezing and specific gravity of raw potatoes. *Journal of Food Science, 51*, 1213.

Ufheil, G., & Escher, F. (1996). Dynamics of oil uptake during deep-fat frying of potato slices. *Lebensmittel Wissenschaft und Technologie, 29*, 640–644.

Warner, K. A., Neff, W. E., & Eller, F. J. (2003). Enhancing quality and oxidative stability of aged fried food with – tocopherol. *Journal of Agricultural and Food Chemistry, 51*(3), 623–627.