

PRODUCTION AND CHARACTERIZATION OF UNRIPE PLANTAIN

(*Musa paradisiaca* L.) FLOURS

Emperatriz Pacheco-Delahaye, Ronald Maldonado, Elevina Pérez and Mily Schroeder

SUMMARY

Four dehydration methods were employed to produce and, then, characterize and compare flours elaborated from commercial unripe plantain (*Musa paradisiaca* L. subsp. *normalis*), variety Harton/Horn. Dehydration of the unripe edible portion of the plantains was completed using tray chamber and double drum dryers, lyophilization (freeze-drying) and microwave oven. The flours obtained were evaluated in their proximate composition, physical characteristics, and rheological and functional properties. The results indicate that the dehydration processes

affected significantly ($p \leq 0.05$) the proximate composition and physical properties of the flours. The rheological and functional properties were different in each of the flours obtained, showing a non Newtonian pseudo-plastic fluid behavior. Since the plantain fruits are important crops in tropical and subtropical regions, the elaboration of flours with differences in their functional properties from the perishable fruit validates these flours as ingredients for different food elaborations, such as the drum dried flour for of instant or quick cooking food.

PRODUCCIÓN Y CARACTERIZACIÓN DE HARINAS DE PLÁTANO (*Musa paradisiaca* L.) INMADURO

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RESUMEN

Se emplearon cuatro métodos de deshidratación para producir y luego caracterizar y comparar harinas producidas con plátano (*Musa paradisiaca* L. subsp. *normalis*) de la variedad Harton/Horn inmaduro (verde). La deshidratación de la parte comestible del plátano inmaduro se completó utilizando deshidratadores de bandeja, doble tambor, liofilización (secado en congelación) y horno de microondas. Las harinas obtenidas fueron evaluadas en cuanto a composición proximal, características físicas, y propiedades reológicas y funcionales. Los resultados indican que el proceso de deshidratación afectó significativamente ($p \leq 0,05$) la composición

proximal y las características físicas de las harinas. Las propiedades reológicas y funcionales fueron diferentes en cada una de las harinas obtenidas, mostrando en solución un comportamiento de fluido no Newtoniano pseudoplástico. Dado que el plátano es un cultivo importante en zonas tropicales y subtropicales, la elaboración de harinas con diferentes propiedades funcionales a partir de la fruta percedera las valoriza como ingredientes para diferentes productos alimenticios, como sería el caso de la harina deshidratada con el deshidratador de doble tambor para usarla como ingrediente en alimentos "instantáneos" o de rápida cocción.

Introduction

Banana plants are monocotyledonous perennial and important crops in the tropical and subtropical world regions (Strosse *et al.*, 2006). They include dessert banana, plantain and cooking bananas. Traded plantain (*Musa paradisiaca* AAB) and other cooking bananas (*Musa* ABB) are almost entirely derived from the AA·BB hybridization of

M. acuminata (AA) and *M. balbisiana* (BB) (Stover and Simmonds 1987; Robinson 1996). Plantain and cooking bananas are very similar to unripe dessert bananas (*M. Cavendish* AAA) in exterior appearance, although often larger; the main differences in the former being that their flesh is starchy rather than sweet, they are used unripe and require cooking (Happi Emaga *et al.*, 2007). Dessert

bananas are consumed usually as ripe fruits; whereas ripe and unripe plantain fruits are usually consumed boiled or fried (Surga *et al.*, 1998).

Banana plantations constitute extensive crops in tropical and Caribbean countries, where they are used as basic food. In Venezuela, the commercial plantain cultivar used is the Harton variety. It is difficult to establish the production volumes, as the

areas where it is grown are dispersed over the country, either in artisanian familiar small areas (*conucos*) or in large areas where it is produced for export. The production of plantain in Venezuela during the ten last years, excluding dessert banana fruits (*cambur*), has been estimated at 5850000ton (FAO, 2004; Agrevo, 2008; MAT, 2008).

New high yield cultivars allow banana plants to be

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PRODUÇÃO E CARACTERIZAÇÃO DE FARINHAS DE PLATANO/BANANA DA TERRA (*Musa paradisiaca* L.) IMATURO

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RESUMO

Empregaram-se quatro métodos de desidratação para produzir e em seguida caracterizar e comparar farinhas produzidas com plátano/banana de terra (*Musa paradisiaca* L. subsp. *normalis*) da variedade Harton/Horn, imaturo. A desidratação da parte comestível do plátano imaturo se completou utilizando desidratadores de bandeja, secadores de tambor duplo, liofilização (secado por congelamento) e forno microonda. As farinhas obtidas foram avaliadas quanto à composição proximal, características físicas, e propriedades reológicas e funcionais. Os resultados indicam que o processo de desidratação afetou significativamente ($p \leq 0,05$) a

composição proximal e as características físicas das farinhas. As propriedades reológicas e funcionais foram diferentes em cada uma das farinhas obtidas, mostrando um comportamento fluido non Newtoniano pseudoplástico. Devido que o plátano é um cultivo importante em zonas tropicais e subtropicais, a elaboração de farinhas com diferenças em suas propriedades funcionais a partir da fruta perecível as valoriza como ingredientes para diferentes produtos alimentícios, como é o caso da farinha secada em tambor para alimentos instantâneos ou de cozimento rápido.

grown more extensively, resulting in a higher economic value, as they respond to plant improvement methods, fertilization and pest and disease control (Gwanfogbe *et al.*, 1988). From the nutritional point of view, these fruits are among the green vegetables with the richest iron and other nutrients contents (Aremu and Udoessien, 1990). However, they are highly perishable and subjected to fast deterioration, as their moisture content and high metabolic activity persist after harvest (Demirel and Turhan, 2003). Air-drying alone or together with sun-drying is largely used for preserving unripe banana. Besides helping preservation, drying adds value to banana. Banana chip is one such value-added product with a crispy and unique taste, consumed as a snack and as an ingredient of breakfast cereals. It can be consumed as produced or further processed by coating with sweeteners, frying, dehydrating or boiling (Demirel and Turhan, 2003). Banana powder is prepared from dessert bananas after mashing and drying the pulp in drum or spray dryers. The dried product is pulverized and passed through a 100-mesh sieve, producing a free-flowing powder which is stable for at least one year after packaging. This powder is used in bakery and confectionery industries, in the treatment of intestinal disorders and in infant diets (Adeniji *et al.*, 2006).

Dehydration is one of the oldest methods of food preservation (Adams, 2004) and converting plantain into flour could contribute to reduce losses and allow the food industry to store the product throughout the year. In order to use plantain flours as ingredients for the food industry it is necessary to characterize their chemical and nutritional composition, as well as their physical, physicochemical, rheological and functional properties.

Instant plantain flours were prepared from ripe and unripe plantain (*M. paradisiaca*) fingers, by cooking and subsequent oven dehydration at 76°C and at 88-92°C, respectively, by Ukun and Ukebor (1991). These authors considered the products as having commercial potential on their own or as ingredients for other foods such as baby weaning foods, puddings, soups and gravies. Gwanfogbe *et al.* (1988) had shown the usage of plantain flour at an industrial level, with full or low starch content, in order to maintain the texture of certain frequently frozen and defrosted foodstuff. Dietary fiber, resistant starch, proteins and mineral contents increase in industrially elaborated cookies when substituting wheat flour by 7% of unripe plantain flour, as shown by Maldonado and Pacheco-Delahaye (2000), who also showed that starch is the main component (84%) of unripe plantain flour,

and reported the content of proteins (6.8%), fats (0.3%), ash (0.5%), and dietary fiber (7.6%). Juárez-García *et al.* (2006) also reported that banana flour was mainly total starch (73.36%) and dietary fiber (14.52%); of the total starch, the available one was 56.29% and resistant starch 17.50%. These authors prepared banana flour bread with a higher content of protein, total starch, resistant starch and indigestible fraction than the control made without banana flour, and indicated that the banana flour is a potential ingredient for bakery products containing slowly digestible carbohydrates.

Plantain starch granules are characterized by extreme shapes, such as irregular, spheroid and elongated granules, with sizes ranging 10-50µm (Pérez, 1997), characteristics that are similar to those found in banana starches (Eggleston *et al.*, 1992).

The present work was aimed at 1) to obtain unripe plantain flours at pilot level using four different dehydration techniques: double drum, freezing and tray chamber drying, and microwave irradiation; 2) to compare the proximate composition, nutritional properties, physical, physicochemical and rheological characteristics of the prepared flours; and 3) to evaluate these flours as ingredients that may guarantee a year-round supply, and encourage the development of new products.

Material and Methods

Raw material

Fifty pounds of unripe (green) plantains (*Musa paradisiaca normalis*) variety Harton/Horn were obtained directly from five marketplaces in Maracay, Aragua State, Venezuela, taking care not to mix them with other varieties. The fruits were chosen of grade 1 maturity stage (unripe) and with acceptable appearance for consumption (Dadzie and Orchard, 1997). Plantains from the five marketplaces were mixed in one batch. They were cleaned, peeled and rinsed with large amounts of tap water, and manually sliced 0.5-1" thick, to be used in the pilot scale production of flours with four different schemes.

Production of unripe plantain flours

1- *Dehydration by freeze-drying (lyophilization)*. Approximately three pounds of plantain slices were transferred to a container and treated with 1% citric acid for 1min. Three independent batches of treated slices were spread out in layers 1cm thick on stainless-steel shelves in a tray-drying accessory and kept at -18°C for 24h, after which they were lyophilized for 5h in a Freezone 4.5 lyophilizer (Labconco; Missouri, USA). The dehydrated product was milled in a hammer mill to a particle size of ~0.01mm. The

flour obtained was stored at $27 \pm 3^\circ\text{C}$ and relative humidity (RH) of $79 \pm 2\%$ in a hermetic glass container, until further analysis (Barbosa-Canovas and Vega-Mercado, 1996; Singh and Heldman, 2001).

2-Dehydration by double drum dryer. Three independent batches of approximately four pounds of sliced plantain were milled to obtain a pulp, using equal amounts of sliced plantains and water. A single drum dryer Speedtrol 20 (Sterling Power System, Inc. Indiana, USA) was fed with milled pulp at 4rpm and 60psi steam pressure (152°C), obtaining a yield of 25% pulp:flour. The dehydrated portion was milled in a hammer mill Fitz Mill model D (Fitzpatrick Company Inc. Chicago, USA), to a particle size of $\sim 0.01\text{mm}$. The flour was stored ($27 \pm 3^\circ\text{C}$, $79 \pm 2\%$ RH) in a hermetic glass container (Barbosa-Canovas and Vega-Mercado, 1996; Singh and Heldman, 2001).

3-Dehydration by irradiation microwave. Three independent batches of approximately one pound of sliced plantain were modified by microwave irradiation following González and Pérez (2002a). Briefly, the moisture was adjusted at 25% in a polyethylene bag; it was then placed in a household microwave oven EM-370T (Sanyo; Tototori, Japan) for 4min at 85°C at one-half of the equipment power (650W, 2450MHz). The temperature was monitored with a thermocouple placed inside the plastic bag. The irradiated portion was milled in a hammer mill (model D above) to a particle size of $\sim 0.01\text{mm}$. The flour obtained was stored at ($27 \pm 3^\circ\text{C}$, RH $79 \pm 2\%$ in a hermetic glass container until further analysis.

4-Conventional dehydration. Three independent batches of approximately five pounds of the sliced edible portions were transferred in one layer to the trays of the chamber of the air convention dehydrator mod. 655159; (Mitchell; Manchester, UK). Over the plantain layer (61.30% moisture) a flow of air at 70°C (air moisture: 0.0265lb/

TABLE I
PROXIMATE COMPOSITION AND CHEMICAL CHARACTERISTICS (%; DB)* OF UNRIPE PLANTAIN FLOURS DEHYDRATED BY FOUR DIFFERENT METHODS**

Parameter	Dehydration methods			
	Lyophilization	Drum dryer	Microwave	Chamber dryer
Moisture	2.36 \pm 0.10c	5.46 \pm 0.11b	6.73 \pm 0.20b	11.75 \pm 0.73a
Ash	1.98 \pm 0.08ab	2.19 \pm 0.047a	1.95 \pm 0.03a	2.02 \pm 0.17a
Crude fat	0.83 \pm 0.01a	0.5 \pm 0.05b	0.17 \pm 0.15d	0.31 \pm 0.01cb
Crude protein***	2.92 \pm 0.10a	3.30 \pm 0.25a	3.12 \pm 0.18a	3.08 \pm 0.08a
Dietary fiber	9.67 \pm 0.05a	9.01 \pm 0.19a	9.43 \pm 0.20a	9.37 \pm 0.45a
Starch	74.65 \pm 2.08c	63.50 \pm 0.55a	64.52 \pm 0.25a	74.30 \pm 2.32ab
Reducing sugars	1.37 \pm 0.18a	1.74 \pm 0.21a	1.65 \pm 1.53a	1.27 \pm 0.53a
Total Sugars	6.98 \pm 0.77b	15.78 \pm 1.50a	14.95 \pm 1.53a	4.23 \pm .67b
Amylose****	38.29 \pm 0.61c	35.84 \pm 0.54a	34.29 \pm 0.51a	33.26 \pm 1.80b
Amilopectin****	61.71	64.16	65.71	66.74

* db: Dry base, except moisture.

** Data are the average of three repetitions \pm standard error. The values in a row followed by the same letter are not statistically different at a significance level of 5%. *** $\text{N} \times 6.25$. **** In base of 100% of starch.

lb dry air, specific volume: $18.51\text{feet}^3/\text{lb}$; and 18.46% of relative air moisture) was applied for 3h or until constant moisture was reached. The dehydrated portion was milled in a hammer mill (model D above) using a 60 mesh screen, to obtain a particle size of approximately 0.01mm. The flour obtained was stored at $27 \pm 3^\circ\text{C}$, RH $79 \pm 2\%$ in a hermetic glass container (Barbosa-Canovas and Vega-Mercado, 1996).

Proximate composition and chemical characteristics

The moisture content of the fresh edible portions, moisture, crude protein ($\text{N} \times 6.25$), crude fat, ash, starch of the flours were analyzed following methods 44-15-A, 46-13, 30-10, 08-01, 76-13, respectively, in AACC (2000). Total dietary fiber was determined using the methodology described by Sigma TDF100A, following the procedures 985.29 and 960.52 in AOACI (1997). The apparent amylose content was determined after Juliano (1971) and AOACI (1997) using potato amylose (Sigma A-3508) as a standard. Amylopectin content was calculated as total starch minus amylose. Total and reduced sugars were determined using the protocol described by Nelson (1944).

Physical and physicochemical properties

Density was determined following Whistler (1964),

and titratable acidity (expressed as $\text{meq} \cdot \text{g}^{-1}$) and pH measured according using procedures 02-31 and 02-52 in AACC (2000). Color measurement was performed with a Macbeth Color-Eye colorimeter equipped with a standard plate tile with parameters $L = 94.64 (\pm 0.3)$, $a = -1 (\pm 0.1)$, $b = 0 (\pm 0.2)$ and $\Delta E = \sqrt{(L)^2 + (a)^2 + (b)^2}$, as described in the Hunter Laboratory Manual (2001).

Functional and rheological properties

Water absorption, soluble solids content and swelling power were determined using combined methods, according to González and Pérez (2002b). The gelatinization profiles of the four flours (10% concentration paste) were evaluated using the Brabender Amylograph, according to method 76-10 in AACC (2000). Initial pasting temperature, range of pasting temperature, peak viscosity, viscosity at 95°C and viscosity at 50°C were the points analyzed from the Amylograph curve (Zhuo *et al.*, 1998). Breakdown, setback and consistency were calculated according to Bhattachary and Sowbhagya (1979). The apparent viscosity of 10% concentration paste starch of the unripe plantain flours was obtained by using a Brookfield viscometer at 30°C (spindle N° 4, and 6, 12, 30 and 60rpm), according to Whistler (1964).

Statistical analysis

Except for the rheology, data collected for each of the three batches of each flour was assessed in triplicate ($n = 3$) and reported as average \pm standard deviation. The data was analyzed by one-way ANOVA followed by Duncan test, carried out with the statistical package SPSS (Chicago, USA), ver. 8.0 of 1997.

Results and Discussion

Proximate composition and some chemical characteristics

Table I summarizes the proximate composition of the plantain flours. The moisture content of the plantain flour obtained by freeze-drying (2.36%) has the lowest value, while the tray chamber dried flour shows the largest one (11.75%). These values are acceptable for the established goal, to reach a stable shelf life ($< 20.0\%$ moisture), and agree with those previously reported (Kayisu *et al.*, 1981; Gwanfogbe *et al.*, 1988; Daramola and Osanyinlusi, 2006). Crude protein and dietary fiber content of the four flours did not show significant differences ($p \geq 0.05$) among them. Gwanfogbe *et al.* (1988) pointed out that the dietary fiber in flours was not affected by the heating treatment. In spite of the low protein content, the high dietary fiber

content makes them of interest from a nutritional point of view. Fruits from banana plants have high fiber and resistant starch content (Higgins *et al.*, 2004; USDA, 2005; Kahlon and Smith, 2007) and their flours are a high dietary fiber source.

Dietary guidelines (USDA, 2000; Marlett *et al.*, 2002) recommend a minimum daily intake of dietary fiber of 25g, equivalent to 12.5g per 1000 calories consumed, which is considerably higher than the estimated intake in western countries (Sungsoo Cho and Dreher, 2001). According to recent surveys (USDA, 2000) the average intake of dietary fiber is 12-17g. Thus, there is the need to increase fiber intake and this has encouraged the use of high-fiber and resistant starch food products.

A high level of dietary fiber and resistant starch in unripe plantain and banana flours has been reported by Vieira da Mota *et al.* (2000), who found 6-15.5% total fiber, and by Suntharalingam and Ravindran (1993) who reported 12.6%. On the other hand, Pacheco-Delahaye and Testa (2005) reported contents of 8.82% and 16.2% of dietary fiber and resistant starch, respectively, in unripe plantain flour. Moreover, the fiber-rich powder made by Rodríguez-Ambriza *et al.* (2008) appears as a promising ingredient for functional foods, as it contains high total dietary fiber and indigestible fraction. Also, research has been carried out in plantain products. Pacheco (2002) found 6.1-6.8% and 14.5-15.1% of dietary fiber and resistant starch, respectively, in green plantain chips. Maldonado and Pacheco (2000) reported increments of 8.65% (from 4.97 to 5.4%) and of 21.05% (from 0.19 to 0.23%) of dietary fiber and resistant starch, respectively, in cookies prepared with substitution of wheat flour by 7% of green plantain flour.

All commercial flours contain trace quantities of inorganic elements, depending on the botanical source and

TABLE II
PHYSICAL AND PHYSICOCHEMICAL PROPERTIES OF UNRIPE PLANTAIN FLOURS DEHYDRATED BY FOUR DIFFERENT METHODS*

Parameter	Dehydration Methods			
	Lyophilization	Drum Dryer	Microwave	Cabinet Dryer
pH	4.6 ±0.1b	5.1 ±0.3a	6.10 ±0.6a	5.10 ±5.10a
Total density (g/ml)	0.58 ±0.10b	0.25 ±0.01c	0.75 ±0.04a	0.71 ±0.07a
Color difference (ΔE)	13.38 ±0.05c	20.92 ±0.04b	23.09 ±0.05a	12.84 ±0.03c

* Data are the average of three repetitions ± standard error. The values in a row followed by the same letter are not statistically different at a significance level of 5%

soil conditions. Ash content is considered among the chemical characteristics that define quality of wheat flour (Peterson *et al.*, 1986, Kent and Evers, 1994). The ash content of wheat flours of high, medium and low grade ranges from 0.35 to 2.3% (Kent and Evers, 1994). As shown in Table I, the ash content did not show significant differences ($P \geq 0.05$) among the four flours, varying from 1.98 to 2.19%, values that are similar to those reported for wheat flours (2.0-2.7% dry basis) by Halverston and Zeleny (1971) and INN (1999). The crude fat content of unripe plantain flour obtained by lyophilization is higher than the other three flours, with statistical differences among them.

The composition of bananas and plantains pulp changes markedly during ripening. Since the amount of sugar in fruits usually increases as they ripen, it can be a useful index of maturity or stage of ripeness. Total sugar content in unripe plantain flour obtained by drum drying and microwave irradiation was higher than that in the other two flours. These differences could be attributed to starch hydrolysis produced by the thermal effect (Alexander, 1995; Waliszewski *et al.*, 2003). Indeed, a reduction in starch content in these flours could be noted, and cannot be attributed to the end of the green-life of the fruit. These results are a guarantee of the unripe state before the dehydration process.

Starch is the principal component (63.50-74.65%) of the unripe plantain flours.

Consequently, these flours are considered as starchy staples food. The differences observed among the four flours are due to the increment of total sugar content in those obtained using the drum-dryer and microwave. The amylose fraction of the freeze-dried flour shows an average of 38.29% (g/100 g of starch), while in the other flours it is slightly lower. Kayisu *et al.* (1981) reported amylose and amylopectin contents of 16.0 and 84.0%, respectively, in banana starch, and Waliszewski *et al.* (2003) reported a 40.70% amylose content in the edible portion of banana. Similar results of the proximate composition of the unripe plantain presented herein were reported by Suntharalingam and Ravindran (1993) for flours produced from the local banana varieties *Alukehel* and *Monthan*, and by Vieira da Mota *et al.* (2000) in different varieties of freeze-dried green banana flours.

Physical and physicochemical properties

Results for the physical and physicochemical properties of the flours are presented in Table II. The dehydration treatments affected significantly the pH and the total density of the flours, as Pérez (1997) reported a density of 1.58g·ml⁻¹ in native starch isolated from unripe plantain. The pH differences could be attributed to depolymerisation caused by the different thermal treatments, hence producing acid terminal residues in the starch molecules. The relatively low densities could

be attributed to total or partial gelatinization of the flours, due to the effect of the thermal treatments. The flour obtained with microwave drying showed a higher density than the other three, which demonstrates a greater compactness of the particles. In contrast, the flour dried in the double drum had a low density. Gelatinization affects density since during the process the granular structure is completely lost (Thomas and Atwell, 1999) and all of the starchy molecules suffer rearrangements that lead to a decrease of the weight by volume unit. The quantification of the relative density and specific gravity of the flours allows the establishment of the flours' functional properties in relation to transport and bin bulk storage, an important factor also for machinery design.

Color is an important physical parameter in flour quality. Flours obtained by double drum and microwave drying are darker than those obtained by freeze-drying. The darkest color was that of the microwave-dried plantain flour. Those obtained in a double drum dryer and microwave oven presented the largest color differences when compared to the standard white plate tile. These results suggest occurrence of the Maillard reaction in the two flours. It can be reasonably presumed that the browning is produced by enzymatic and non-enzymatic reactions that usually take place in the food. In spite of the color differences observed in the flours, their color was not differentiable by visual observation from the color of

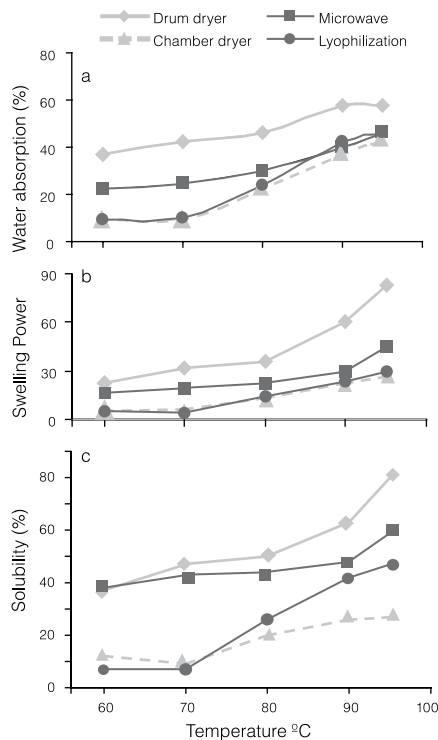


Figure 1. Water absorption (a), swelling power (b) and soluble solids (c) of dehydrated unripe plantain flours.

the edible portion of the unripe plantain, even after color differences had been detected with the white tile standard. The limited browning reaction taking place could be due to a lower availability of reducing sugar and amino acids for the Maillard reaction and to the inactivation of the enzymes that contribute to the browning.

Functional and rheological properties

Figures 1a, b and c show the temperature dependence of water absorption, swelling power and solid soluble contents of the four unripe plantain flours. The water absorption patterns of the flours obtained using the tray chamber dryer and lyophilization show two well defined stages (Figure 1a). During the first stage (60-70°C) water absorption did not increase. It can be assumed that throughout this stage, the water molecules reversibly reach the amorphous zones of the granular structure, causing the rupture or weakening of intermo-

lecular forces inside the starch granules. This high water absorption at low temperature makes the flour obtained in double drum dryer a suitable ingredient for quick preparations or instant food (Alexander, 1995).

The swelling patterns of the flour obtained using the tray dryer and freeze-drier are similar, with a progressive swelling at the interval of temperatures evaluated and a similar behavior to the water absorption profile (Figure 1b). Kayisu *et al.* (1981) also reported two stages in unripe plantain starch, one at <70°C and another, more noticeable, at 70-75°C. The starchy dehydrated flour using the drum dryer exhibits a higher swelling pattern than those shown by the rest. It should be pointed out that the drum drying treatment produces a total disruption of the granular structure of the starches (Colonna *et al.*, 1984). However, it is observed (Figure 1b) that even with a high disruption level of the flour particles elaborated with the double drum dryer, a second stage of energetic relaxation was required (from

80 to 95°C). For the microwave-irradiated flour, a mild swelling of the granule developed in the first stage (from 60 to 90°C) and a sudden increase took place in the second stage, from 90 to 95°C. This could be due to the presence of remaining strong bounding forces at the crystalline zones.

For the microwave-irradiated flour, a mild swelling of the granule developed in the first stage (from 60 to 90°C) and a sudden increase took place in the second stage, from 90 to 95°C. This could be due to the presence of remaining strong bounding forces at the crystalline zones.

The soluble amylograph curves of dehydrated unripe plantain flours.

The curves show a progressive increment with temperature, with two stages of molecular dispersion, the more marked one from 80% onwards. The thermal treatments produce the collapse of the bounding forces among starch granules, enabling them to lose integrity and permitting amylose molecules to leach and disperse in greater proportion in the medium. Here again, the flours obtained by microwave and drum-drying show higher levels than the other two. The results reflect the existence of two types of bonds with different bounding forces inside the starch granules of these flours. The soluble solids curves reported for plantain native starch (Kayisu *et al.*, 1981; Pérez, 1997) showed patterns of behavior and temperature ranges comparable to the ones shown in Figure 1c.

Gelatinization profiles

The plots of the Amylograph curves of the unripe plantain flours are depicted in Figure 2. Except for the drum-dried flour which had an initial pasting temperature of 63°C, that of the other three flours was reached during the holding time at 95°C. The lyophilized flour showed a high peak of maximum vis-

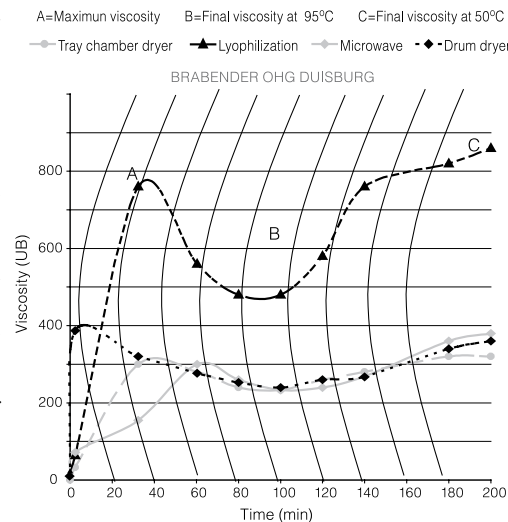


Figure 2. Amylograph curves of dehydrated unripe plantain flours.

cosity at 95°C (A in Figure 2) and a sharp viscosity reduction during the holding time (at 95°C for 20min; A to B), with a value of 470UB. Pérez (1997) reported a stable viscosity in plantain native starch during the plot presenting a breakdown equal to zero. This difference is explained by the type of sample used in each of these two studies. Except for the lyophilized flour, the overall viscosity of the other three flours showed relatively similar patterns after they had reached maximum viscosity. The flours obtained using the tray chamber dryer and lyophilizer increased their viscosity from zero (30°C) to a peak at 95°C, with values of 310 and 780UB, respectively. The drum dried flour developed an initial viscosity of 400UB at 30°C, while the microwave irradiated one started to developed 100UB at 30°C, increasing a peak of 300UB during the holding time at 95°C. This rheological profile coincided with the description by Alexander (1995) of the so-called "pregelatinized" or "pre-cooked" starches, referred to in the group which, when mixed with water at room temperature, provides a rapid viscosity increase without a thermal process. This property is important for industrial appli-

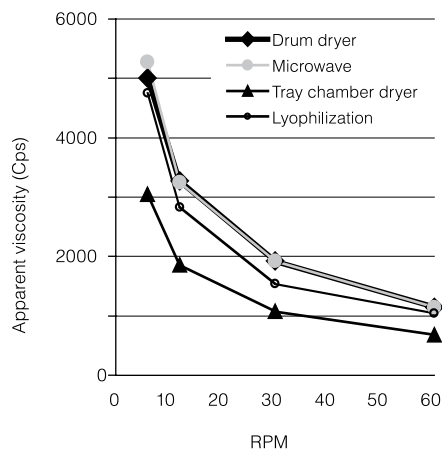


Figure 3. Apparent viscosity (cps) of dehydrated unripe plantain flours.

cations in instant or quick cooking products. The flour obtained by the tray chamber dryer demonstrated the highest stability during the setting or retrogradation, followed by the flour obtained with lyophilization and finally the flour treated by the double drum dryer and microwave oven.

Apparent viscosity

The viscosity of a liquid system is its resistance to flow due to internal friction. The so-called viscosity of a starch solution is the combined effect of a number of inherent properties. The effect results from the residual granular particles of new colloidal groupings that take place during the starch cooking process. Many starches possess a varying grade of thixotropy, which is the property of the starch paste becoming thinner with agitation or under shear. In starch paste, the observed viscosity depends upon the shearing rate. As the main flour component is starch, it will be the principal responsible for the viscosity. The aqueous slurry of the flours had a marked tendency to behave as a pseudo-plastic fluid; in which the apparent viscosity decreased as a function of the shear rate increment (Figure 3). This is common for starch or starchy solutions due to their thixotropy. On the other hand, when comparing

the results of apparent viscosity in all flours, the microwave and double drum dried flours had higher viscosity than the other two. It was expected that these two flours would develop less viscosity than the other two, as a function of the starch content. It can thus be inferred that the formation of residual granular particles from new colloidal groupings, increasing viscosity, took place in different ways under microwave and drum-drying.

Conclusion

The results obtained confirm the feasibility of producing starch flour with moisture contents with adequate levels for a stable shelf life. These flours have considerable contents of dietary fiber and starch, as well as different functional behaviors that make them of interest as ingredients for food production. The results also show that the functional properties of the flours are affected by the different thermal treatments. Moreover, information is made available for the applicability of the flours as a function of their different functional properties, as resulting effects of the different treatments. Data about rheological properties demonstrates that the dehydration treatment of the edible portion of plantain incremented the flour starch granule stability in the cooking process at high temperatures, a relevant condition for industrial processing. Also, the drum dryer flour has the properties of a pre-gelatinized or "pre-cooked" flour, an important advantage for ready-to-eat products.

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