Available online at www.sciencedirect.com
ScienceDirect
Food Chemistry 103 (2007) 590–600
Food Chemistry
www.elsevier.com/locate/foodchem

Effects of the stage of maturation and varieties on the chemical composition of banana and plantain peels

Thomas Happi Emaga [a,b,*], Rado Herinavalona Andrianaivo [a], Bernard Wathelet [a], Jean Tchango Tchango [b], Michel Paquot [a]

[a] Unité de Chimie Biologique Industrielle, Faculté Universitaire des Sciences Agronomiques de Gembloux, Passage des déportés, 2, B-5030 Gembloux, Belgium
[b] Centre Africain de Recherche sur Bananier et Plantain (CARBAP), BP 832 Douala, Cameroon

Received 31 March 2006; received in revised form 8 June 2006; accepted 1 September 2006

Abstract

A study of the chemical composition of six varieties of fruit peels of the banana and plantain: dessert banana (*Musa* AAA), plantain (*Musa* AAB) cooking banana (*Musa* ABB) and hybrid (*Musa* AAAB) at three stages of ripeness, was carried out in order to explore their potential applications. The varieties did not affect chemical constituents in a consistent manner. Peel of the six varieties was rich in total dietary fibre (TDF) (40–50%). The protein content in peel of the banana and plantain was 8–11%. Leucine, valine, phenylalanine and threonine were essential amino acids in significant quantities. Lysine was the limiting amino acid. The content of lipid varied from 2.2% to 10.9% and was rich in polyunsaturated fatty acids, particularly linoleic acid and α-linolenic acid. Potassium was the most significant mineral element. Peel of plantain was richer in starch than were the banana peels. Maturation of fruits involved increase in soluble sugar content and, at the same time, decrease in starch. The degradation of the starch under the action of the endogenous enzymes, may explain the increase in the soluble sugar content. Further investigations on the composition and the physiological functions (using animal-feeding experiments) of these dietary fibres must be considered.

Keywords: Banana; Plantain; Peel; Maturation; Varieties; Dietary fibre; α-Linolenic

1. Introduction

Banana and plantain constitute the principal food resources in the world. These cultures occupy the Fourth world rank of the most significant foodstuffs after rice, corn and milk (FAO, 1999; INIBAP, 2002). Banana trees are produced in large quantities in tropical and subtropical areas. World production of *Musa* in 2003 was estimated at 102 millions tons, of which about 68% was classified as bananas and 32% as plantains (FAO, 2003).

Banana is a general term embracing a number of species or hybrids in the genus *Musa* of the family *Musaceae*. Almost all of the known edible-fruited cultivars arose from two diploid species, *Musa acuminata* (AA) and *Musa balbisiana* (BB). Moreover, there are diploid, triploid and tetraploid hybrids composing subspecies of *M. acuminata*, and subspecies between *M. acuminate* and *M. balbisiana* (Robinso, 1996; Stover & Simmonds, 1987). Dessert bananas for world food trade are almost entirely derived from genetic make ups of *Musa acuminate* of triploid character, indicated as AAA. Plantain (*Musa AAB*) and other cooking bananas (*Musa ABB*) are also triploid and derived from the AA × BB hybridisation. Plantain and cooking bananas are very similar to unripe dessert bananas in outward appearance, although often larger. The major differences are that their flesh is starchy rather than sweet, that they are used unripe, and require cooking.

* Corresponding author. Address: Unité de Chimie Biologique Industrielle, Faculté Universitaire des Sciences Agronomiques de Gembloux, Passage des déportés, 2, B-5030 Gembloux, Belgium. Tel.: +32 81622232; fax: +32 81622231.
E-mail addresses: guythappi@yahoo.fr, happiemaga.t@fsagx.ac.be (T. Happi Emaga).

0308-8146/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.foodchem.2006.09.006

In Africa, the main producers are Uganda and Cameroon. In Cameroon, the production of bananas and plantains represents the second agricultural economic resource of the country after wood (FAO, 2001); the introduction of new varieties and improvement of farming techniques have contributed to the increase in outputs, especially an increase in the production of plantain. This is estimated at 2.25 million tons (FAO, 2002). Before any form of use, the fruits of the banana trees, in general, are peeled and the peelings can be discarded, given to cattle or cooked, or eventually composted (Bakry et al., 1997). In addition, the development of the processing industries of bananas and plantains (chips, flours, pulps dried, and jam, spirits distilled from wine or beer) is growing in Cameroon and other African countries. Significant quantities of banana or plantain peels, equivalent to 40% of the total weight of fresh banana, are for these reasons generated (Tchobanoglous, Theisen, & Vigil, 1993). It is thus significant and even essential to find applications for these peels. Moreover, these peels cause a real environmental problem (Zhang, Whistler, BeMiller, & Hamaker, 2005). Nowadays, there is little mention of their use in the literature. Potential application of these peels depends on their chemical composition. The attention of researchers is focused on the pulp (Bello-Perez, Pano de leon, Agama-Acevo, & Paredes-Lopez, 1998; Kayisu & Hood, 1981; Lii, Chang, & Young, 1982; Zhang et al., 2005) and peels. However, some papers deal with different practical applications of banana peels, e.g. production of alcohol (Tewari, Marwaha, & Rupal, 1986), methane (Bardiya & Somayaji, 1996; Nallathanbi Gunaseelan, 2004), food for livestock (Onwuka, Adetiloye, & Afolami, 1997) or adsorbents for water purification (Annadurai, Juang, & Lee, 2002; Annadurai, Juang, & Lee, 2004). The composition of bananas and plantains pulp changes dramatically during ripening. In addition, the fruits of the banana tree are consumed at the green, average ripe and ripe stages. Loeseck (1950) classified banana ripening into eight stages according to peel colour. Hence, it is clearly necessary to evaluate the effect of the stage of maturation on peel compounds. This constitutes a significant element during recovery and storage of peels.

Moreover, little information is available on the varietal influence and little is known about the metabolic changes during maturation.

For these reasons, the present research aimed at determining chemical composition, at three stages of maturation. Different genomics and varieties were also studied.

2. Materials and methods

2.1. Sample preparation

The fruits peels used in this study were from six varieties of banana trees. All the varieties were obtained from CARBAP, Cameroon. The fruit peels of the *Musa* Genus: French Clair (FC), Grande Naine (GN), Big Ebanga (BE), pélipita (PPT), Yankambi Km5 (YKm5), and CRBP039 (039), were obtained at three different stages of ripeness: stage 1 (Green), stage 5 (More yellow than green), stage7 (yellow/a few brown spots). These stages of ripening are most used in industrial transformations and traditional culinary preparations. The accession and morphotaxonomic descriptors of these varieties are given in Table 1.

Several bunches of the six varieties were collected in the fields. The first two hands of each bunch were removed. Stages of maturation of the fruits were followed in the laboratory at temperatures between 20 °C and 25 °C. The fruits were washed, and separated into pulp and peel. The peels obtained were dried at 60 °C for 24 h, then stored in polypropylene plastic bags at room temperature before use.

2.2. Chemical analysis

The ash content of the peel (3 g) was estimated according to AOAC method 4.1.10 (AOAC, 2002). Moisture was determined by drying to a constant weight at 105 °C.

Neutral lipids were extracted in a Soxtherm S306 AK Automatic Extractor System Gerhardt (Germany) for 4 h, using 140 ml of petroleum ether (boiling range: 40–60 °C). The extracted lipids were heated at 103 ± 2 °C in an oven for 1 h and determined gravimetrically.

Total nitrogen content (N) was determined using the standard Kjeldahl procedure (AOAC, 1990), by nitrogen

Table 1
Accession and morphotaxonomic descriptors of six varieties (Jeff et al., 2001)

Varieties	Species/ group	Subspecies/ subgroup	Origin	Fruit position	Mature fruit peel colour	Number fruit	Fruit type
French Clair (FC)	AAB	Plantain	Cameroon	Perpendicular to the stalk	Bright yellow	≥17	Cooking
Big Ebanga (BE)	AAB	Plantain	Cameroon	Perpendicular to the stalk	Bright yellow	≥12	Cooking
Grande Naine (GN)	AAA	Cavendish	–	Curved upward	Bright yellow	≥17	Dessert
Yankambi Km5 (Ykm5)	AAA	Ibota	Democratic Republic of Congo	Curved upward	Bright yellow	≥17	Dessert
Pelipita (PPT)	ABB	Pelipita	–	Curved upward	Yellow	≥17	Cooking
CRBP039 (039)	AAAB	Plantain hybrid	CARBAP Cameroon	–	Yellow	≥17	Cooking

determination after mineralization (with a 1000 Kjeltabs MQ tablet and a Digestion System 20, 1015 Digester, Tecator, AB, Höganäs Sweden) and distillation (by a Kjeltec Auto 1030 Analyser, Tecator, AB, Höganäs, Sweden). Crude protein was expressed as $6.25 \times N$.

The concentrations of sodium, potassium, calcium, magnesium, zinc, iron, copper and manganese were determined using a flame atomic absorption spectrophotometer (Perkin–Elmer, 2380) according to the Benton and Vernon method (Benton & Vernon, 1990). For the phosphorus content, the Murphy Riley reagent method was used (Murphy & Riley, 1962).

Total amino acids composition of the peel of flours was obtained after hydrolysis under nitrogen with 6 N HCl at 110 °C during 24 h (Kaiser, Gehrke, Zumbalt, & Kuo, 1974) and an analysis of the amino acids in a Stein and Moore HPLC (Biochrom 20 Plus, Pharmacia, Cambridge, UK). Norleucine (500 nM) was added as internal standard. The hydrolysates were injected into a cation-exchange column; the amino acids, separated by elution with suitable buffers of increasing pH, were detected with ninhydrin in a continuous flow photometric analytical system at 570 and at 440 nm (only for proline) and quantified by references (Sigma) used as calibration standards.

Sulphur amino acids (cysteine and methionine) were determined as cysteic acid and methionine sulphone, respectively, by a Biochrom 20 Plus (Pharmacia, Cambridge, UK) amino acid analyser. Before the acid hydrolysis, a performic oxidation was done.

Tryptophan was determined after alkaline hydrolysis of the proteins and a SP 8800 HPLC (Spectra physics, San Jose, CA, USA) analysis at 280 nm, with a XTERRA RP18 (4.6×150 mm; 3.5 μm) column. The temperature of the column was kept at 45 °C and the injection volume was 5 μl. Flow rate was 1 ml/min with a mixture of solvent A (760 ml of sodium acetate buffer (0.07 M)/triethanolamine (0.025% v/v) adjusted to pH 4.5 with glacial acetic acid + 40 ml of methanol) and solvent B (acetonitrile containing 0.05% (w/v) trifluoroacetic acid). The following gradients (solvent A/solvent B/min) were used: 0/100/0; 0/100/10; 50/50/5; 50/50/5; 0/100/5; 0/100/5. Separated tryptophan was quantified by using α-methyl-tryptophan as reference.

The protein quality of banana peel was evaluated by calculating the chemical score (or amino acid score). It characterises the balance of essential amino acids. The chemical score is the analytically determined level of the first-limiting amino acid, expressed as a percentage of the level of the same amino acid recommended in the Provisional Reference Pattern. We used FAO/WHO (1990) Provisional Reference Pattern, to evaluate the protein.

Fatty acid composition was determined by using a GLC, according to IUPAC Method No.: 2.301 (IUPAC, 1990). GC analyses were performed using a Hewlett–Packard 6890 series Gas Chromatograph System equipped with a HP-INNOWAX capillary column ($30\ m \times 0.25$ mm, film thickness 0.32 μm). Derivatized extracts (1.0 μl) in hexane were injected into the column. The oven temperature was programmed from 50 (isothermal for 1 min) to 150 °C at 30 °C min^{-1} and from 150 °C to 240 °C (isothermal for 10 min) at 4 °C min^{-1}. Compounds were detected using a flame ionisation detector at 325 °C. Helium was used as carrier gas at a flow rate of 65 ml/min. Identification and quantification of fatty acid methyl esters was accomplished by comparing the retention times of the peaks with those of standards of Supelco 37 component FAME Mix 1 ml (Supelco Inc., Bellefonte, PA, USA).

Starch contents of fruits peels were determined by the official method of EWERS (Iso 10520, 1997). The method includes a double determination; the sample was first treated (hot) with diluted HCl. After defecation and filtration, the optical activity of the solution was measured, with three recoveries, in the Bellingham polarimeter in a tube of 200 mm; the sample was then extracted with ethanol (40%). After acidification of the filtrate using HCl, defecation and filtration, the optical activity was measured. The difference between the two measurements, multiplied by the known factor, gave the content of starch in the sample. In this case, a saccharimeter of the German type was used. The following factors: N (Weight (g) of saccharose in 100 ml of water producing an optical rotation of 100 saccharimeter degrees measured using a tube of 200 mm) = 26.00 G and $[\alpha_D^{20}]$ (Specific optical rotation of the pure starch) = 184.0.

Total dietary fibre (TDF) and insoluble dietary fibres (IDF) were analysed according to AOAC methodology (Prosky, Asp, Schweizer, DrVries, & Furday (1992)). Soluble dietary fibre (SDF) was calculated as TDF minus IDF (Prosky et al. (1992)). In brief, peel sample, suspended in buffer, was sequentially digested by heat-stable α-amylase, protease, and amyloglucosidase to remove starch and protein. IDF was recovered from the enzyme digestate after filtration. SDF in the filtrate was precipitated with ethanol and filtered. All dietary fibre (DF) fractions collected were dried. These DF contents were corrected for residual protein, ash, and blank.

Soluble sugars were quantified via high-performance liquid chromatography (HPLC). Standards for quantification included sucrose, fructose and glucose. Samples were homogenized with water for 24 h and centrifuged at 2790*g* for 30 min at 25 °C. The extract was filtered through 0.45 μm Millipore filters and a 25 μl sample was injected for current HPLC analysis of sugars. Eluted monosaccharides were quantified by the Dionex DX500 HPLC system, using a Carbopac PA-10 column (250×4 mm). The mobile phase consisted of 40 mM sodium hydroxide at a flow rate of 1 ml/min. The injection volume was 25 μl, and detection of components was compared to an external standard with a regression factor equal to or greater than 0.999.

The statistical analysis could not be completed on the data set. However, to maintain quality control during chemical analyses, the error between duplicate samples was determined. If the error between duplicate samples

Table 2
Proximate composition (% dry matter, DM) in the fruit peels of different varieties and maturity stage

Varieties	FC			BE			GN			Ykm5			PPT			039		
Stage	1	5	7	1	5	7	1	5	7	1	5	7	1	5	7	1	5	7
Dry matter	12.6 ± 0.8	14.2 ± 0.1	14.8 ± 0.2	12.7 ± 0.2	14.7 ± 0.4	18.7 ± 0.2	8.7 ± 0.1	8.9 ± 0.8	10.2 ± 0.2	7.7 ± 0.1	8.0 ± 0.8	12.9 ± 0.3	11.8 ± 0.1	11.8 ± 0.6	21.4 ± 1.0	9.6 ± 0.1	9.5 ± 0.4	11.1 ± 0.5
Crude protein	8.3 ± 01	9.1 ± 01	9.1 ± 0.2	8.1 ± 0.2	8.4 ± 0.1	8.6 ± 0.1	6.3 ± 0.1	6.6 ± 0.3	8.1 ± 0.2	6.9 ± 0.1	7.4 ± 0.2	7.9 ± 0.1	9.5 ± 0.1	11.2 ± 0.1	10.7 ± 0.1	9.8 ± 0.4	10.6 ± 0.1	11.0 ± 0.2
Crude fat	4.6 ± 01	5.6 ± 0.1	5.9 ± 0.1	2.2 ± 0.1	3.7 ± 0.1	3.6 ± 0.0	3.8 ± 0.1	5.8 ± 0.1	5.7 ± 0.2	6.3 ± 0.1	8.6 ± 0.3	10.9 ± 0.1	4.2 ± 0.1	6.3 ± 0.0	7.0 ± 0.03	5.3 ± 0.2	6.8 ± 0.1	7.8 ± 0.2
Total ash	8.8 ± 0.2	7.9 ± 0.4	8.2 ± 0.3	6.4 ± 0.2	7.5 ± 0.3	7.4 ± 0.2	9.6 ± 0.2	11.1 ± 0.2	12.8 ± 0.5	10.4 ± 0.3	10.8 ± 0.3	10.7 ± 0.2	9.3 ± 0.3	9.2 ± 0.4	7.7 ± 0.5	7.5 ± 0.2	11.0 ± 0.5	8.2 ± 0.3

was greater than 5%, the analysis was repeated. The results were expressed as means ± SD (standard deviation).

3. Results and discussion

3.1. Proximate composition

Table 2 summarizes, the proximate composition of six varieties of banana and plantain peels at different maturation stages. It clearly appears that the two plantain varieties (FC and BE) have higher dry matter than have the dessert banana varieties (GN and YKm5). The dry matter ranged from 12.6% to 18.7% for the plantain while it ranged from 7.7% to 12.9% for the banana. The hybrid (039) had a low dry matter content, similar to the banana one. The cooking banana (PPT) has very high dry matter content (21.4%) at stage 7.

Dry matter increased (12.6–14.8% for FC, 12.7–18.7% for BE, 8.7–10.2% for GN, 7.7–12.9% for Ykm5, 11.8–21.4% for PPT and 9.5–11.1% for 039) during the process of ripening. There is no information about the influence of the maturation stage on the dry matter of banana and plantain peels in the literature. On the other hand, it is well established that the dry matter decreases for the pulp with maturation (Trease & Evans, 1989). Moreover, according to Loeseck (1950) and Fernandes et al. (1979), there is an increase in water content of the pulp, derived from carbohydrates utilized during breathing and osmotic transfer from the peel to the pulp. This occurs as a marked difference in osmotic pressure between peel and pulp, because the sugar content increases more rapidly in the pulp than in the peel.

Similarly the dry matter content increase, slight increases in crude fat (4.6–5.9% for FC and from 6.3% to 10.9% for GN) and crude protein (8.3–9.1% for FC and 6.3–8.1% for Ykm5) contents were observed. That slight increase in crude protein was also observed by Adisa and Okey (1987) in their research on banana (variety not being specified) fruit peel (1.5 on day 1, 14.1 on day 5% and 15.0% on day 7 of ripening). The PPT and the hybrid 039 had higher crude protein contents (more than 10%) especially at stages 5 and 7. All other varieties had crude protein contents below 10% (means of 8.8 for FC, 8.3 for BE, 7.0 for GN, 7.4 for YKm5). Essien, Akpan, and Essien (2005) studied the crude protein content of one sweet ripened banana, without specifying its variety, and obtained 7.8%. This result is in good agreement with our result at stage 7.

The crude fat concentrations were notably lower than were those observed (11.1%) by Essien et al. (2005) except for YKm5 (10.9%). All the other results were below 9%. This may be due to the differences in varieties and geographical factors. Nevertheless, the crude lipid of the fruit peels was found to be higher than those of some other fruit peels (2.2% for citrus sinensis L.Cv. Liucheng) (Chau & Huang, 2003). In all varieties, the stage 7 has the highest crude fat content (Table 2).

Table 3
Concentrations of TDF, IDF and SDF in the fruit peels of different varieties and maturation stage

Varieties	FC			BE			GN			Ykm5			PPT			039		
Stage	**1**	**5**	**7**	**1**	**5**	**7**	**1**	**5**	**7**	**1**	**5**	**7**	**1**	**5**	**7**	**1**	**5**	**7**
TDF (%)	32.9 ± 0.8	39.4 ± 1.2	46,9 ± 0.9	35.9 ± 0.2	35.7 ± 0.9	37.3 ± 0.6	43.2 ± 0.5	49.6 ± 0.1	49.7 ± 0.3	49.9 ± 3.5	51.9 ± 1.2	47.9 ± 1.3	37.3 ± 1.1	43.3 ± 1.2	39.7 ± 0.9	39.9 ± 0.7	39.3 ± 0.5	36.9 ± 0.4
IDF (%)	27.3 ± 0.1	34.4 ± 1.4	40.0 ± 1.0	29.7 ± 0.8	30.4 ± 0.4	31.3 ± 0.3	36.5 ± 0.9	42.4 ± 1.2	42.9 ± 0.7	36.3 ± 1.6	39.9 ± 1.0	35.2 ± 1.4	29.2 ± 1.2	31.2 ± 3.1	30.9 ± 0.3 ±	27.7 ± 0.5	30.7 ± 1.9	29.3 ± 1.4
SDF (%)	5.6	5.1	6.9	6.2	5.3	6.7	7.0	7.1	6.8	13.6	12.0	13.7	8.1	12.1	8.8	12.2	8.6	7.6

Table 4
The mean ± SE content (% dry matter, DM) of individual sugars and starch in the fruit peels of different varieties and maturation stage

Varieties	FC			BE			GN			Ykm5			PPT			039		
Stage	**1**	**5**	**7**	**1**	**5**	**7**	**1**	**5**	**7**	**1**	**5**	**7**	**1**	**5**	**7**	**1**	**5**	**7**
Starch	35.4 ± 0.0	26.5 ± 0.2	3.2 ± 0.0	39.3 ± 0.05	24.0 ± 0.05	0.1 ± 0.03	11.1 ± 0.1	8.1 ± 0.1	3.3 ± 0.1	14.0 ± 0.1	12.6 ± 0.02	2.6 ± 0.12	36.0 ± 0.5	6.7 ± 0.30	0.4 ± 0.03	37.6 ± 0.6	10.9 ± 0.05	0.3 ± 0.02
Glucose	0.8 ± 01	4.8 ± 01	15.6 ± 0.2	2.0 ± 0.2	8.6 ± 0.1	14.5 ± 0.1	1.0 ± 0.3	10.6 ± 0.4	14.0 ± 0.2	0.8 ± 0.1	10.8 ± 0.1	10.8 ± 0.1	0.4 ± 0.1	7.7 ± 0.1	12.0 ± 0.1	0.3 ± 0.1	7.1 ± 0.1	15.2 ± 0.1
Fructose	0.7 ± 01	7.3 ± 01	26.6 ± 0.2	2.2 ± 0.2	14.8 ± 0.1	23.8 ± 0.1	1.2 ± 0.1	14.3 ± 0.3	18.4 ± 0.2	0.3 ± 0.1	12.0 ± 0.1	12.4 ± 0.1	0.1 ± 0.1	13.7 ± 0.1	21.4 ± 0.1	0.1 ± 0.1	14.0 ± 0.1	22.5 ± 0.2
sucrose	0.2 ± 01	0.1 ± 0.1	ND	0.1 ± 0.1	0.1 ± 0.1	ND	1.5 ± 0.3	0.5 ± 0.2	ND	0.3 ± 0.1	0.2 ± 01	ND	0.4 ± 0.1	0.2 ± 01	ND	0.5 ± 0.1	0.5 ± 0.1	ND

ND, not detected.

The ash content of fruit peels ranged from 6.4% to 12.8% with a mean of 8.75. GN variety has the highest value (12.8% at stage 7). Hammond, Egg, Diggins, and Coble (1996) reported an ash content of 10.1% for one sweet banana. The results remained stable during maturation for certain varieties (FC, BE, PPT and Ykm5) whereas, for other varieties (GN and 039), they increased during maturation (9.6–12.8% for GN, 7.5–11.0% for 039) (Table 2). These observed changes during banana ripening are in agreement with the literature findings of Hammond et al. (1996) on the levels of the dessert banana peels.

3.2. Dietary fibre

The total dietary fibre (TDF), insoluble dietary fibre (IDF) and soluble dietary fibre (SDF) contents are given in Table 3. TDF is important for all the studied varieties (32.9–51.9%), and is higher in the banana group than in plantain. Higher values are observed in YKm5 (51.9%). In all varieties IDF was the dominant fibre fraction. IDF values represent ± 75% of TDF for all varieties. These peel fibre (IDF) might possibly give pronounced effects on intestinal regulation and stool volume, which are related to the consumption of insoluble fibre (Schneeman, 1987). Similarly, IDF was also found to be a large fibre fraction in the peels of some other fruits (Gorinstein et al., 2001; Grigelmo-Miguel & Matin-Bellosco, 1999a; Grigelmo-Miguel & Matin-Bellosco, 1999b). Among the different varieties, YKm5 had the highest SDF content ± 13% while plantain (FC and BE variety) had a SDF content ranging from 5% to 7%. The peel of culled bananas and plantains could be a rich, low-cost source of dietary fibre, mainly hemicelluloses and pectin polysaccharides (Zhang et al., 2005). Evaluation of the chemical composition of the fibre fraction might confirm this hypothesis.

The stage of maturation did not affect TDF, IDF and SDF of varieties in a consistent manner (Table 3). For example, TDF increased in FC (32.9–46.9%), GN (43.2–49.7%), BE (35.9–37.3%) and PPT (37.3–43.3%) varieties, but decreased in Ykm5 (51.9–47.9%) and 039 (39.9–36.9%). Here, it is difficult to compare the plantains and bananas because, inside the banana group, there is a difference between YKm5 and GN.

3.3. Starch and soluble sugars

The mean individual sugars and starch contents in fruit peels of different varieties and maturation stage are given in Table 4.

During maturation, starch decreased considerably (Fig. 1) from stage 1 to stage 7 (39.3–0.1% for BE, 11.1–3.3% for GN). Simultaneously, the soluble sugar content increased in different proportions (4.2–38.3% for BE, 2.2–32.4% for GN). This synchronism can be explained by the degradation of the starch and the formation of free sugars under the action of the enzymes. The disappearance of the starch reserve during banana ripening appears to be relatively rapid because of the activities of several enzymes working together. According to Terra, Garcia, and Lajolo (1983) and Cordenunsi and Lajolo (1995), amylase, glycosidase, phosphorylase, sucrose synthase and invertase can act in the degradation of starch and the formation and accumulation of soluble sugars. Regina and Glória (2005) observed the same trends, from green to ripe (15.7–3.4% DM) on "Prata" banana pulp. According to Loeseck (1950), starch levels can vary with stage of maturity, variety of fruit, cultivation and ripening conditions. In the first stage of maturation, the plantain group had a higher starch content (35.4–39.3% at stage 1, 24.0–26.5 at stage 5) than had the banana group (11.1–14.0 at stage 1; 8.1–12.6 at stage 5). A similar pattern was observed in the pulp (FAO, 1972).

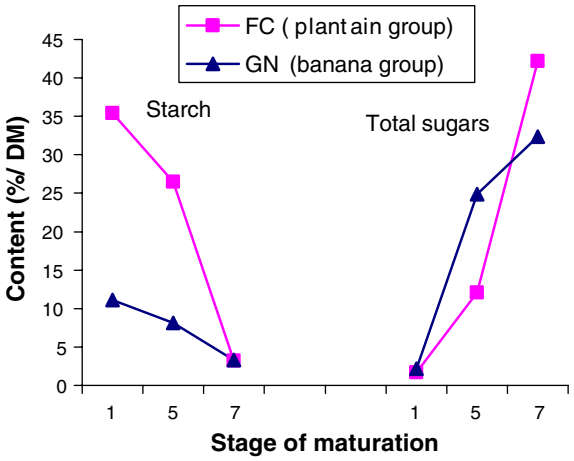

Fig. 1. Level of starch and total soluble sugars in peel fruits of FC (plantain group) and YKm5 (banana group) variety during maturation.

HPLC chromatographic profiles of all varieties at different maturity stages were qualitatively the same; only three types of soluble sugars were detected in fruit peels. The main sugars were glucose and fructose. The glucose ranged from 0.3% to 15.6% with a mean of 7.8. The fructose ranged from 0.1% to 26.6%. The variety FC peel (stage 7) (15.6% and 26.6% for glucose and fructose, respectively) had the highest glucose and fructose contents of all varieties compared. The content of fructose was higher than was glucose in all varieties. Adisa and Okey (1987) observed this tendency on the banana peels. Previous studies showed that, in banana pulp, glucose, fructose and sucrose were present (Fernandes, Carvalho, & Cal-Vidal, 1979; Terra et al., 1983; Mota, Lajolo, & Cordenunsi, 1997; Regina & Glória, 2005; Schneeman, 1987). Sucrose levels were lower than other sugars in the ripened fruits. Fernandes et al. (1979) also observed that sucrose levels were lower than glucose and fructose levels in ripened "prata" banana.

3.4. Amino acids composition

Table 5 summarizes the profiles of the amino acids in the fruit peels of different varieties. Taking into consideration

Table 5
Amino acid composition (%DM) in the fruit peels of different varieties and maturation stage

Varieties	BE			FC			GN			YKm5			PPT			039		
Stage	1	5	7	1	5	7	1	5	7	1	5	7	1	5	7	1	5	7
Essential amino acids																		
Leu	0.41 ± 0.01	0.38 ± 0.01	0.40 ± 0.0	0.40 ± 0.01	0.41 ± 0.00	0.40 ± 0.002	0.30 ± 0.0	0.32 ± 0.00	0.38 ± 0.0	0.33 ± 0.0	0.34 ± 0.0	0.37 ± 0.0	0.31 ± 0.0	0.37 ± 0.0	0.35 ± 0.0	0.44 ± 0.0	0.49 ± 0.0	0.45 ± 0.0
Val	0.33 ± 0.01	0.32 ± 0.0	0.35 ± 0.0	0.29 ± 0.00	0.35 ± 0.00	0.33 ± 0.00	0.24 ± 0.01	0.28 ± 0.01	0.32 ± 0.02	0.26 ± 0.0	0.26 ± 0.0	0.31 ± 0.0	0.31 ± 0.0	0.37 ± 0.0	0.35 ± 0.0	0.40 ± 0.01	0.55 ± 0.01	0.45 ± 0.01
Thr	0.34 ± 0.0	0.32 ± 0.0	0.33 ± 0.01	0.30 ± 0.0	0.33 ± 0.0	0.31 ± 0.0	0.20 ± 0.02	0.22 ± 0.0	0.28 ± 0.0	0.22 ± 0.0	0.23 ± 0.0	0.24 ± 0.0	0.28 ± 0.0	0.32 ± 0.0	0.31 ± 0.0	0.29 ± 0.04	0.34 ± 0.0	0.34 ± 0.03
Phe	0.30 ± 0.02	0.30 ± 0.01	0.30 ± 0.01	0.30 ± 0.01	0.33 ± 0.0	0.31 ± 0.0	0.19 ± 0.0	0.21 ± 0.0	0.25 ± 0.0	0.21 ± 0.0	0.21 ± 0.0	0.22 ± 0.0	0.27 ± 0.0	0.32 ± 0.0	0.31 ± 0.0	0.34 ± 0.0	0.34 ± 0.0	0.34 ± 0.01
Ile	0.23 ± 0.01	0.21 ± 0.01	0.22 ± 0.00	0.22 ± 0.01	0.23 ± 0.0	0.22 ± 0.0	0.15 ± 0.0	0.17 ± 0.0	0.21 ± 0.01	0.18 ± 0.0	0.19 ± 0.0	0.20 ± 0.0	0.22 ± 0.0	0.26 ± 0.0	0.24 ± 0.0	0.29 ± 0.0	0.33 ± 0.0	0.30 ± 0.0
Lys	0.17 ± 0.0	0.13 ± 0.0	0.12 ± 0.0	0.24 ± 0.0	0.15 ± 0.0	0.11 ± 0.0	0.19 ± 0.0	0.11 ± 0.0	0.14 ± 0.0	0.22 ± 0.0	0.16 ± 0.0	0.17 ± 0.0	0.25 ± 0.0	0.16 ± 0.0	0.14 ± 0.0	0.36 ± 0.01	0.19 ± 0.01	0.14 ± 0.01
His	0.14 ± 0.0	0.15 ± 0.0	0.13 ± 0.0	0.16 ± 0.0	0.14 ± 0.0	0.11 ± 0.0	0.13 ± 0.0	0.10 ± 0.0	0.12 ± 0.0	0.20 ± 0.0	0.13 ± 0.0	0.16 ± 0.0	0.20 ± 0.0	0.17 ± 0.0	0.16 ± 0.0	0.33 ± 0.0	0.19 ± 0.0	0.15 ± 0.0
Trp	0.07 ± 0.0	0.10 ± 0.0	0.10 ± 0.0	0.09 ± 0.0	0.10 ± 0.0	0.14 ± 0.0	0.07 ± 0.0	0.09 ± 0.0	0.09 ± 0.0	0.08 ± 0.0	0.08 ± 0.0	0.08 ± 0.0	0.10 ± 0.0	0.11 ± 0.0	0.08 ± 0.0	0.09 ± 0.0	0.09 ± 0.0	0.10 ± 0.0
Met	0.07 ± 0.01	0.06 ± 0.01	0.05 ± 0.01	0.07 ± 0.0	0.05 ± 0.0	0.06 ± 0.0	0.05 ± 0.0	0.07 ± 0.01	0.05 ± 0.01	0.06 ± 0.0	0.05 ± 0.0	0.06 ± 0.0	0.07 ± 0.0	0.08 ± 0.0	0.07 ± 0.0	0.07 ± 0.0	0.06 ± 0.0	0.05 ± 0.0
$\sum_1$	**2.1**	**2.0**	**2.0**	**2.1**	**2.1**	**2.0**	**1.6**	**1.6**	**1.9**	**1.8**	**1.7**	**1.8**	**2.1**	**2.1**	**2.7**	**2.6**	**2.6**	**2.3**
Nonessential amino acids																		
Glu	0.95 ± 0.02	0.89 ± 0.0	1.04 ± 0.03	1.30 ± 0.01	1.46 ± 0.07	0.99 ± 0.02	0.70 ± 0.02	0.70 ± 0.01	1.10 ± 0.03	0.64 ± 0.02	0.65 ± 0.0	1.01 ± 0.03	1.36 ± 0.0	1.30 ± 0.2	1.07 ± 0.01	1.48 ± 0.0	1.69 ± 0.01	1.14 ± 0.0
Asp	0.78 ± 0.01	0.72 ± 0.01	0.75 ± 0.01	0.92 ± 0.00	0.91 ± 0.01	0.89 ± 0.00	0.54 ± 0.02	0.56 ± 0.00	0.69 ± 0.01	0.50 ± 0.02	0.52 ± 0.0	0.62 ± 0.01	2.18 ± 0.0	1.55 ± 0.0	1.54 ± 0.0	1.20 ± 0.03	0.86 ± 0.01	0.80 ± 0.03
Gly	0.39 ± 0.0	0.38 ± 0.0	0.37 ± 0.01	0.40 ± 0.00	0.44 ± 0.01	0.45 ± 0.01	0.27 ± 0.01	0.31 ± 0.00	0.37 ± 0.01	0.25 ± 0.01	0.29 ± 0.0	0.33 ± 0.0	0.33 ± 0.0	0.38 ± 0.0	0.37 ± 0.0	0.38 ± 0.02	0.44 ± 0.0	0.41 ± 0.0
Ala	0.36 ± 0.0	0.33 ± 0.0	0.34 ± 0.0	0.39 ± 0.01	0.40 ± 0.01	0.40 ± 0.00	0.27 ± 0.01	0.31 ± 0.01	0.38 ± 0.02	0.25 ± 0.00	0.28 ± 0.0	0.32 ± 0.01	0.39 ± 0.0	0.46 ± 0.0	0.44 ± 0.0	0.41 ± 0.01	0.45 ± 0.01	0.40 ± 0.01
Ser	0.34 ± 0.0	0.32 ± 0.0	0.34 ± 0.01	0.37 ± 0.01	0.40 ± 0.01	0.41 ± 0.00	0.25 ± 0.01	0.28 ± 0.00	0.34 ± 0.01	0.23 ± 0.01	0.26 ± 0.0	0.30 ± 0.0	0.35 ± 0.0	0.38 ± 0.0	0.38 ± 0.0	0.32 ± 0.06	0.37 ± 0.0	0.38 ± 0.01
Pro	0.33 ± 0.02	0.30 ± 0.0	0.31 ± 0.01	0.34 ± 0.00	0.37 ± 0.01	0.37 ± 0.01	0.24 ± 0.00	0.26 ± 0.01	0.32 ± 0.03	0.22 ± 0.0	0.24 ± 0.0	0.27 ± 0.01	0.31 ± 0.0	0.39 ± 0.0	0.33 ± 0.0	0.69 ± 0.06	0.74 ± 0.0	0.74 ± 0.03
Arg	0.24 ± 0.0	0.19 ± 0.0	0.17 ± 0.0	0.31 ± 0.01	0.27 ± 0.00	0.16 ± 0.00	0.20 ± 0.02	0.14 ± 0.00	0.21 ± 0.00	0.18 ± 0.0	0.13 ± 0.0	0.18 ± 0.0	0.27 ± 0.0	0.26 ± 0.0	0.22 ± 0.0	0.31 ± 0.02	0.29 ± 0.01	0.22 ± 0.01
Tyr	0.17 ± 0.0	0.15 ± 0.0	0.14 ± 0.0	0.19 ± 0.01	0.19 ± 0.00	0.18 ± 0.01	0.12 ± 0.01	0.11 ± 0.01	0.15 ± 0.00	0.11 ± 0.0	0.11 ± 0.0	0.14 ± 0.0	0.15 ± 0.0	0.18 ± 0.0	0.16 ± 0.0	0.22 ± 0.0	0.18 ± 0.01	0.16 ± 0.01
Cys	0.15 ± 0.0	0.15 ± 0.0	0.16 ± 0.0	0.10 ± 0.01	0.12 ± 0.01	0.12 ± 0.00	0.08 ± 0.01	0.10 ± 0.01	0.11 ± 0.00	0.8 ± 0.0	0.10 ± 0.0	0.11 ± 0.0	0.12 ± 0.0	0.14 ± 0.0	0.13 ± 0.0	0.13 ± 0.0	0.16 ± 0.0	0.16 ± 0.0
$\sum_2$	**3.7**	**3.4**	**3.6**	**4.3**	**4.6**	**4.0**	**2.7**	**2.8**	**3.7**	**3.2**	**2.6**	**3.3**	**5.5**	**5.0**	**4.6**	**5.1**	**5.2**	**4.4**
$\sum$	**5.8**	**5.4**	**5.6**	**6.4**	**6.7**	**6.0**	**4.3**	**4.4**	**4.6**	**4.9**	**4.2**	**5.1**	**7.5**	**7.1**	**7.2**	**7.8**	**7.8**	**6.7**

$\sum_1$, sum of the determined essential amino acids; $\sum 1$, sum of the determined nonessential amino acids; $\sum = \sum 1 + \sum 2$.

these results, all the essential amino acids are present in the peels of the six varieties according to the classification of FAO (1991). The sum of essential amino acid of fruit peels ranged from 1.7% to 2.6% (mean = 2.1), whereas nonessential amino acid ranged from 2.6% to 5.5% (mean = 4.0). Sum of nonessential amino acid (±70% of total amino acids) was higher than was that of essential amino acid (±30% of total amino acids); 039 variety (stage 5) had the highest sum of amino acids values of the varieties compared. In addition, the varieties having a higher percentage of protein were in general those having high amino acid contents. The dominant essential amino acids in the peel were Leu, Val, Phe and Thr.

The quantity of protein determined by the method of Kjeldahl was much higher than the sum of the amino acids. This could be explained by the fact that the method of Kjeldahl determines all N compounds, not only proteins or amino acids, which leads to an over estimation of the protein content. There exist other N compounds than protein. Kanazawa and Sakakibara (2000) and Someya et al. (2002) have for example, shown that banana peels contain large quantities of antioxidants (1% DM), e.g. dopamine. The dopamine may reach 0.5 g per 100 g.

In general, total amino acid content of the peel did not show a marked change with stage of maturation.

The essential amino acid content is compared to the standard protein value of the FAO/WHO in Table 6. The chemical index ranged from 20.8 to 63.3. Any essential amino acid with a value lower than the FAO standard protein value could be considered as a limiting concentration. In all varieties and stages of maturation, the lysine had a lower value than other essential amino acids. Hence it is the limiting amino acid.

Chemical index decreased from stage 1 to stage 7. Our results clearly indicate that banana and plantain peels have a good quality protein at stage 1 of maturation.

3.5. Mineral elements

Table 7 shows the relative concentration of minerals (ppm dry matter) in the fruit peels of different varieties and maturity stages. The mineral matters are classified into two major groups: the macroelements and microelements (trace elements).

The amounts of potassium, phosphorus, magnesium and calcium were high, while iron, zinc, manganese and copper contents were low. Potassium (55,234–63,521 mg kg^{-1}) was the most abundant element in the peel of the six varieties, followed by phosphorus, calcium, and magnesium. John and Marchal (1995) have also shown that peels of bananas have a high content of potassium (compared to Ca, P, and Mg). The banana group (GN and YKm5 varieties) had the highest value of Ca, hence it had a higher Ca/P (2–4) than had plantain group (±1). The trace elements, in descending order by quantity, were Fe (16.9–39.1 mg kg^{-1}), Zn (14.3–34.2 mg kg^{-1}), Mn (6.79–34.0 mg kg^{-1}) and Cu (0.80–2.80 mg kg^{-1}). These

Table 6
Amino acid score in the fruit peels of different varieties and maturation stage on the basis of value FAO/WHO (1990)

	Protein of ref. essential amino acids (mg/1 g)	Thr **34**	Val **35**	Met + Cys **25**	Ile **28**	Leu **66**	Tyr + Phe **63**	His **19**	Lys **58**	Trp **11**	Chemical index
BE	1	123.5	116.4	108.6	101.4	76.7	92.1	91.0	36.0	78.6	**36.0**
	5	112.0	108.8	100.0	89.3	68.5	85.0	94.0	26.7	108.2	**26.7**
	7	112.9	116.3	97.7	91.4	70.5	81.2	79.6	24.1	105.7	**24.1**
FC	1	106.3	99.8	86.7	94.7	73.0	93.7	101.5	49.9	98.6	**49.9**
	5	106.7	109.9	74.7	90.3	68.3	90.7	81.0	28.4	99.9	**28.4**
	7	100.2	103.6	79.1	86.3	66.6	85.5	63.6	20.8	139.9	**20.8**
GN	1	93.4	108.8	78.7	85.0	69.7	55.4	108.6	52.0	69.9	**52.0**
	5	93.6	121.2	104.8	92.0	73.5	57.7	79.7	28.7	124.0	**28.7**
	7	90.8	112.9	81.0	92.6	71.1	54.9	78.0	27.7	101.0	**27.7**
Ykm5	1	93.8	107.7	81.2	93.2	72.5	73.6	152.6	55.0	79.1	**55.0**
	5	91.4	100.4	81.1	91.7	69.6	68.6	92.5	37.3	61.4	**37.3**
	7	89.4	112.1	86.1	90.4	71.0	72.3	106.6	37.1	69.0	**37.1**
PPT	1	86.7	93.2	80.0	82.7	49.4	70.2	110.8	45.4	95.7	**45.4**
	5	84.0	94.4	78.6	82.9	50.1	70.9	79.9	24.6	89.3	**24.6**
	7	85.2	93.5	92.2	80.1	49.6	71.2	78.7	22.6	68.0	**22.6**
039	1	87.0	116.6	81.6	105.7	68.0	90.7	177.2	63.3	83.5	**63.3**
	5	94.3	148.2	83.0	111.2	70.0	77.9	94.3	30.9	77.2	**30.9**
	7	90.9	106.9	76.4	97.4	62.0	72.2	67.0	21.9	82.6	**21.9**

values are in agreement with the values reported by Selema and Farago (1996) for one plantain variety, but are lower than the limiting contents found in food of vegetable origin determined by Jean-Blain (2002). This may be due to differences in varieties and to environmental factors. The biological roles of a number of trace elements have been reported. Mn and Fe are essential elements for both plants and animals (Valkovic, 1978). Some of these elements serve as prosthetic groups of some enzymes.

The potassium content increased slightly during maturation (Table 7). For example, it ranged from 5.7% DM at stage 1–6.3% DM at stage 7 for GN and from 4.6% DM at stage 1–5.5% DM at stage 7 for FC. The other mineral elements did not show as pronounced a change with stage of maturation.

3.6. Fatty acid composition

Fatty acid compositions of the oil extracted from the fruit peels of different varieties and maturation stage are given in Table 8, which shows that linoleic acid (omega-6) and α-linolenic acid (omega-3) account for more than

Table 7
Elemental composition (mg kg^{-1} DM) of the ash in the fruit peels of different varieties and maturity stage

Varieties	Stage	K	Ca	P	Mg	Na	Fe	Cu	Zn	Mn
FC	**1**	45,891 ± 208	1742 ± 0	2020 ± 70	828 ± 0	501 ± 77	20.4 ± 2.7	1.0 ± 0.2	15.4 ± 0.3	11.5 ± 0.3
	5	47,934 ± 582	1742 ± 0	1960 ± 62	888 ± 15	477 ± 15	28.6 ± 1.9	1.2 ± 0.2	17.4 ± 0.3	14.4 ± 0.9
	7	55,234 ± 468	1654 ± 81	3364 ± 16	1101 ± 73	690 ± 56	30.1 ± 1.4	0.9 ± 0.0	17.9 ± 1.0	12.5 ± 1.0
BE	**1**	46,710 ± 28	2150 ± 353	2020 ± 113	740 ± 28	510 ± 0.0	24.4 ± 1.0	1.1 ± 0.1	23.9 ± 0.9	10.9 ± 0.6
	5	47,785 ± 544	1500 ± 141	1780 ± 85	695 ± 7	360 ± 85	19.6 ± 1.2	0.9 ± 0.0	20.1 ± 0.6	7.7 ± 0.3
	7	47,725 ± 403	2250 ± 221	1760 ± 14	695 ± 49	510 ± 14	24.4 ± 4.9	1.1 ± 0.1	18.6 ± 0.3	12.7 ± 0.6
GN	**1**	57,246 ± 93	5954 ± 81	2099 ± 38	1047 ± 0	654 ± 15	30.7 ± 3.9	1.3 ± 0.3	16.0 ± 0.6	14.9 ± 0.3
	5	54,814 ± 851	4824 ± 843	1989 ± 69	1165 ± 23	472 ± 69	26.8 ± 3.9	1.3 ± 0.0	15.9 ± 0.0	16.8 ± 0.6
	7	63,521 ± 557	3769 ± 80	2081 ± 47	1378 ± 8	456 ± 39	35.5 ± 6.7	2.0 ± 0.0	19.7 ± 1.9	22.1 ± 0.3
Ykm5	**1**	48,105 ± 134	6450 ± 707	1770 ± 42	1265 ± 7	390 ± 85	30.9 ± 1.2	2.4 ± 0.0	32.8 ± 0.9	27.9 ± 0.6
	5	57,725 ± 361	7200 ± 567	2050 ± 28	1385 ± 21	525 ± 92	27.2 ± 1.2	3.0 ± 0.1	37.6 ± 0.0	28.3 ± 1.1
	7	52,135 ± 587	8150 ± 212	1830 ± 28	1795 ± 49	565 ± 21	40.3 ± 3.6	2.8 ± 0.1	38.8 ± 0.3	37.0 ± 0.6
PPT	**1**	49,285 ± 106	1900 ± 282	3540 ± 42	1810 ± 14	510 ± 49	22.5 ± 2.4	1.4 ± 0.1	31.0 ± 0.3	10.3 ± 0.3
	5	50,815 ± 205	2450 ± 212	3575 ± 7	1910 ± 0.0	410 ± 85	20.6 ± 2.4	1.1 ± 0.3	27.4 ± 0.3	12.0 ± 0.8
	7	44,250 ± 141	1750 ± 495	3540 ± 7	1895 ± 35	420 ± 42	16.8 ± 2.4	1.0 ± 0.1	28.3 ± 0.9	10.9 ± 0.6
039	**1**	47,150 ± 820	3950 ± 707	2600 ± 42	1070 ± 0.0	375 ± 35	27.2 ± 0.8	1.2 ± 0.1	23.9 ± 0.3	21.1 ± 0.3
	5	51,675 ± 7	1400 ± 0.0	2770 ± 71	1020 ± 14	490 ± 85	31.9 ± 2.4	1.2 ± 0.1	17.0 ± 0.6	12.5 ± 0.3
	7	54,820 ± 867	1700 ± 2828	2530 ± 438	1020 ± 14	510 ± 0.0	34.7 ± 3.6	1.2 ± 0.1	19.9 ± 0.3	13.5 ± 0.6

Table 8
Fatty acid (% of total FA content) composition in the fruit peels of different varieties and maturation stages

Varieties	FC			BE			GN			YKm5			PPT			039		
Stage	1	5	7	1	5	7	1	5	7	1	5	7	1	5	7	1	5	7
Lauric (12:0)	0.8 ± 0.1	0.5 ± 0.1	ND	0.7 ± 0.0	0.5 ± 0.0	ND	1 ± 0.2	0.7 ± 0.0	0.7 ± 0.0	0.4 ± 0.0	0.5 ± 0.0	ND	0.8 ± 0.0	0.9 ± 0.0	ND	0.8 ± 0.0	0.4 ± 0.0	0.7 ± 0.0
Myristic (14:0)	5.2 ± 0.3	0.8 ± 0.1	0.9 ± 0.2	3.2 ± 0.1	4.2 ± 0.1	4.1 ± 0.1	4.3 ± 0.4	4.7 ± 0.3	4.6 ± 0.3	2.8 ± 0.3	3.1 ± 0.3	2.2 ± 0.1	1.2 ± 0.4	2.6 ± 0.8	2.8 ± 0.4	1.8 ± 0.4	2.1 ± 0.4	2.3 ± 0.3
Pentadecanoic (15:0)	1.8 ± 0.5	0.5 ± 0.3	ND	0.8 ± 0.1	1.1 ± 0.1	ND	3.1 ± 0.8	1.2 ± 0.4	ND	1.1 ± 0.3	0.9 ± 0.01	ND	O.9 ± 0.1	1.0 ± 0.1	ND	0.5 ± 0.1	0.6 ± 0.1	0.1 ± 0.0
Palmitic (16:0)	38.1 ± 1.4	38.7 ± 0.9	37.2 ± 3.4	39.1 ± 0.1	39.3 ± 1.2	41.9 ± 0.4	38.2 ± 2.2	40.8 ± 2.4	41.5 ± 3.8	34.3 ± 0.9	35.4 ± 1.1	35.2 ± 1.0	35.4 ± 1.3	35.3 ± 0.8	36.6 ± 0.3	38.2 ± 0.4	36.3 ± 0.8	38.2 ± 0.5
Stearic (C18:0)	3.7 ± 0.0	3.5 ± 0.8	4.5 ± 0.9	2.8 ± 0.4	2.6 ± 0.3	2.3 ± 0.0	5.3 ± 1.2	3.9 ± 0.6	3.4 ± 0.8	2.3 ± 0.5	3.2 ± 0.8	3.0 0.9	2.8 ± 0.3	3.8 ± 0.5	2.5 ± 0.2	2.2 ± 0.8	2.5 ± 0.6	5.2 ± 1.0
Arachidic (C20:0)	2.1 ± 1.0	1.4 ± 0.6	ND	ND	ND	ND	ND	0.7 ± 0.8	1.4 ± 0.1	ND	ND	ND	ND	ND	ND	ND	ND	ND
% Saturated fatty acids	51.8	43.4	42.6	46.6	47.7	48.3	51.9	51.9	51.8	40.9	43.1	40.4	41.1	43.6	45.5	43.0	41.9	46.2
Oleic (C18:1)	4.1 ± 0.0	4.2 ± 0.7	6.1 ± 2.2	4.4 ± 0.3	3.5 ± 0.4	4.2 ± 0.2	4.2 ± 1.1	3.2 ± 0.8	3.2 ± 1.1	4.3 ± 0.8	3.7 ± 1.1	3.5 ± 1.2	4.6 ± 0.3	4.0 ± 0.4	9.6 ± 0.0	2.0 ± 0.2	3.3 ± 0.1	4.0 ± 0.1
% Mono-unsaturated fatty acids	4.1 ± 0.0	4.2 ± 0.7	6.1 ± 2.2	4.4 ± 0.3	3.5 ± 0.4	4.2 ± 0.2	4.2 ± 1.1	3.2 ± 0.8	3.2 ± 1.1	4.3 ± 0.8	3.7 ± 1.1	3.5 ± 1.2	4.6 ± 0.3	4.0 ± 0.4	9.6 ± 0.0	2.0 ± 0.2	3.3 ± 0.1	4.0 ± 0.1
Linoleic (C18:2)	23.9 ± 0.6	23.2 ± 1.1	22.2 ± 3.2	21.3 ± 1.1	21.8 ± 1.2	21.2 ± 1.0	22.7 ± 4.9	22.4 ± 1.5	23.9 ± 4.0	22.3 ± 1.2	24.8 ± 0.7	25.3 ± 0.3	22.5 ± 05	24.8 ± 0.2	22.3 ± 1.1	23.0 ± 0.0	26.9 ± 0.2	26.3 ± 0.6
α-linolenic (C18:3)	20.2 ± 1.1	29.3 ± 1.6	29 ± 1.7	27.1 ± 1.3	28.3 ± 1.4	27.5 ± 1.2	21.1 ± 1.9	22.5 ± 3.7	21.2 ± 1.9	20.8 ± 1.3	19.7 ± 0.5	20.8 ± 0.2	22.9 ± 0.1	24.3 ± 0.3	22.6 ± 0.4	27.6 ± 0.3	25.3 ± 0.4	25.5 ± 0.1
% Poly-unsaturated fatty acids	44.1	52.4	51.2	48.4	50.1	48.7	43.8	44.9	45.1	42.1	44.5	46.1	45.4	49.1	49.9	50.6	52.2	51.8

ND, not detected.

40% (42.1–52.2%) of the total fatty acids in all varieties. It is notable that the α-linolenic acid was identified by a standard. Fruit peel oil is rich in the polyunsaturated essential fatty acids. In this study, saturated acids ranged from 40.4% to 51.9% of total fatty acids. Among them, the main saturated acids were palmitic and stearic, with small amounts of arachidic and myristic. It is interesting to note, however, that the unsaturated fatty acids were especially made up of polyunsaturated fatty acids which are of nutritional interest, because they cannot be synthesized de novo by animals and have to be obtained from plants by diet (Moore, 1993). Linoleic acid has a beneficial effect on blood lipids, lowering blood pressure and serum cholesterol. The nutritional value of linoleic acid is due to its metabolism at tissue levels which produces the hormone-like prostaglandins (Ramadan & Mörsel, 2002). Numerous investigators have described the role of α-linolenic acids in health promotion and disease prevention (Simopoulos, 1999a; Simopoulos, 1999b).

The stage of maturation did not affect fatty acid composition of any varieties in a consistent manner (Table 8). When harvested at stage 7, saturated fatty acids decreased in FC and YKm5 varieties but increased in BE; GN and 039 varieties. Polyunsaturated fatty acids increased slightly in the banana group (43.8–45.1% for GN and 42.1–46.1% for YKm5), but decreased slightly in the plantain group from stage 5 to stage 7 (52.4–51.2% for FC and 50.1–48.7% for BE).

4. Conclusion

Knowledge of the qualitative and quantitative distribution of the chemical constituents is of capital importance for a reliable evaluation of the peels of the fruits of the banana tree. However, detailed reports on the chemical composition of the peels of these fruits have not been previously forthcoming. From the results, we can conclude that fruit peels have a high content of dietary fibre, mainly insoluble dietary fibre (IDF). Besides a high dietary fibre content, starch is important at the first stage of maturation but decreases as the total sugars increase with maturation. Among the minerals, potassium is the most important. All varieties present a significant quantity of unsaturated fatty acids mainly linoleic acid and α-linolenic acid. For certain chemical constituents, we have observed a difference between the dessert banana (AAA) and plantain (AAB) groups. The stage of maturation did not affect chemical elements of any varieties in a consistent manner.

At this stage, it is difficult to come to a final conclusion about the evaluation of banana and plantain peels. A first solution is to use them as an energy source, regarding their high fibre content. We also note that banana and plantain peels have a good protein quality and constitute a qualitatively interesting lipidic source. Hence another solution is to use them in livestock feed formulations. The peel of these fruits could also be exploited as a good source of dietary fibre. A finer analysis of the component structures in

relation to their techno-functionalities will be useful. It might be useful to obtain nitrogen compounds other protein or amino acids and also antioxidants. Nevertheless, our results show that the banana and plantain peels cannot be regarded as "waste", as is the current practice in Cameroon.

Acknowledgements

Financial support was provided for this study by the Commission Universitaire pour le Developpement (CUD) Belgium. The authors are also grateful to the Department of Food Technology (Gembloux Agricultural University, Belgium), to the laboratory of post-harvest technology, CARBAP, Cameroon and Maryse Hardenne for her assistance.

References

Adisa, V. A., & Okey, E. N. (1987). Carbohydrate and protein composition of banana pulp and peel as influenced by ripening and mold contamination. *Food Chemistry, 25*, 85–91.

Annadurai, G., Juang, R. S., & Lee, D. J. (2002). Use of cellulose-based wastes for adsorption of dyes from aqueous solutions. *Journal of Hazardous Materials, 92*, 263–274.

Annadurai, G., Juang, R. S., & Lee, D. J. (2004). Adsorption of heavy metals from water using banana and orange peels. *Water Science and Technology, 47*, 185–190.

AOAC (Association of Official Analytical Chemist) (1990). *Official methods of analysis* (15th ed.). Washington, VA: AOAC.

AOAC (Association of Official analytical Chemist) (2002). *Official methods of analysis* (17th ed.). Washington, DC: AOAC.

Bakry, F., Carrel, F., Caruana, M. L., Cote, F. X., Jenny, C., Tezenas, D. H. (1997). Les bananiers. Amélioration des plantes tropicales (pp. 109–139), CIRAD-ORSTOM.

Bardiya, N., & Somayaji, k. (1996). Biomethanation of banana peel and pineapple waste. *Bioresource Technology, 58*, 73–76.

Bello-Perez, L. A., Pano de leon, Y., Agama-Acevo, E., & Paredes-Lopez, O. (1998). Isolation and partial characterization of amaranth and banana starches. *Starch/Staerke, 50*, 409–413.

Benton, J. J., & Vernon, W. C. (1990). Sampling, handling and analyzing plant tissue samples. In: R. L. Waeterman, (Ed.), *Soil testing and plant analysis* (3rd ed.). SSSA Book Series No. 3.

Chau, C. F., & Huang, Y. L. (2003). Comparison of the chemical composition and physicochemical properties of different fibers prepared from the peel of *citrus sinensis L. Liucheng*. *Journal of Agricultural and Food Chemistry, 51*, 215–218.

Cordenunsi, B. R., & Lajolo, F. M. (1995). Starch breakdown during banana ripening: sucrose synthase and sucrose phosphate synthase. *Journal of Agricultural Food Chemistry, 43*, 347–351.

Essien, J. P., Akpan, E. J., & Essien, E. P. (2005). Studies on mould growth and biomass production using waste banana peel. *Bioresource Technology, 96*, 1451–1455.

FAO (Food and Agriculture Organization of the United Nations). (1972). Planification et évaluation des programmes de nutrition appliquée. Etudes de nutrition de la FAO No. 26, Rome.

FAO (Food and Agriculture Organization of the United Nations). (1991). Racines, tubercules, plantains et bananes dans la nutrition humaine. Collection FAO: Alimentation et nutrition No. 24, Rome.

FAO (Food and Agriculture Organization of the United Nations). (1999). Statistic Series 52. Yearbook Production (Vol. 117, pp. 254). Agriculture, Rome, Italy.

FAO (Food And Agriculture Organization of the United Nations). (2001). FAOSTAT statistics database, Agriculture, Rome, Italy.

FAO (Food and Agriculture Organization of the United Nations). (2002). FAOSTAT statistics data base, Agriculture, Rome, Italy.

FAO (Food And Agriculture Organization of the United Nations). (2003). FAOSTAT statistics database, Agriculture, Rome, Italy.

FAO/WHO. (1990). Report of the joint expert consultation on protein quality evaluation. FAO, 4–8 December, Rome.

Fernandes, K. M., Carvalho, V. D., & Cal-Vidal, J. (1979). Physical changes during ripening of silver banana. *Journal of Food Science, 44*(4), 1254–1255.

Gorinstein, S., Matin-Bellosco, O., Park, Y. S., haruenkit, R., Lojek, A., Ciz, M., et al. (2001). Comparison of some biochemical characteristics of different citrus fruits. *Food Chemistry*, 309–313.

Grigelmo-Miguel, N., & Matin-Bellosco, O. (1999a). Comparison of dietary fiber from by-products of processing fruits and greens and from cereals. *LEBENSMITTEL-WISSENSCHAFT and TECHNOLOGIE, 32*, 503–508.

Grigelmo-Miguel, N., & Matin-Bellosco, O. (1999b). Characterisation of dietary fiber from orange juice extraction. *Food Research International, 31*, 355–361.

Hammond, J. B., Egg, R., Diggins, D., & Coble, G. C. (1996). Alcohol from bananas. *Bioresource Technology, 56*, 125–129.

INIBAP (International Network For The Improvement Of Banana And Plantain). (2002). Net Working Banana and Plantain: INIBAP Annual Report 2001, Montpelier, France.

Iso 10520. (1997). Native starch-determination of starch content-Ewers polarimetric method.

IUPAC (International Union of Pure and Applied Chemistry). (2004). Standard methods for the analysis of oils, fats and derivatives. Oxford: Pergamon Press. 1990; *Technol, 37*, 657–661.

Jean-Blain, C. (2002). Introduction à la nutrition des animaux domestiques, Edition Médicales Internationales (Cachan) et Technique and Documentation (Paris). p. 424.

Jeff, D., Christophe, J., Deborale, K., Kodjo-Tomekpe. (2001). Musalogue. A Catalogue of Musa germplasm. Diverty in the genus Musa. p. 123.

John, P., & Marchal, L. (1995). Ripening and biochemistry of the fruit. In S. Gowen (Ed.), *Bananas and plantains* (pp. 434–467). London: Chapman and Hall.

Kaiser, F. E., Gehrke, Ch. W., Zumbalt, R. W., & Kuo, K. C. (1974). Amino acid analysis. Hydrolysis, ion-exchange clean-up, dérivatisation and quantitation by gas–liquid chromatography. *Journal of Chromatography A, 94*, 113–133.

Kanazawa, K., & Sakakibara, H. (2000). High content of dopamine, a strong antioxidant, in Cavendish banana. *Journal of Agricultural Food Chemistry, 48*, 844–848.

Kayisu, K., & Hood, L. F. (1981). Characterization of starch and fiber of banana fruit. *Journal of food Science, 46*, 1885–1890.

Lii, C. Y., Chang, S. M., & Young, Y. L. (1982). Investigation of the physical and chemical properties of banana starches. *Journal of Food Science, 47*, 1493–1497.

Loeseck. (1950). Chemical changes during ripening bananas. *Chemistry physiology and technology, 4* (p. 67–118). New York: Interscience.

Moore, T. S. (1993). *De novo fatty acid biosynthesis in lipid metabolism in plant*. Boca Raton, FL: CRC press, p. 3–32.

Mota, R. V., Lajolo, F. M., & Cordenunsi, B. R. (1997). Composição em carbohidratos de alguns cultivares de banana (Musa spp.) durante o amadurecimento. *Ciência Technologia de Alimentos, 17*(2), 94–97.

Murphy, J., & Riley, J. P. (1962). A modified single solution method for determination of phosphate in natural waters. *Analytica Chimica Acta, 27*, 31–36.

Nallathanbi Gunaseelan, V. (2004). Biochemical methane potential of fruits and vegetable solid waste feedstocks. *Biomass and Bioenergy, 26*, 389–399.

Onwuka, C. F. I., Adetiloye, P. O., & Afolami, C. A. (1997). Use of household wastes and crop residues in small ruminant feeding in Nigeria. *Small Ruminant Research, 24*, 233–237.

Prosky, L., Asp, N. G., Schweizer, T. G., DrVries, J. W., & Furday, I. (1992). Determination of insoluble and soluble fiber in food and

foodproducts: Collaborative study. *Journal of The Association of Official Analytical Chemists, 75*, 360–366.

Ramadan, M. F., & Mörsel, J. F. (2002). Neutral lipids classes of blackcumin (*Nigella sativa L.*) seed oils. *European Food Research and Technology, 214*, 202–206.

Regina, C. A., & Glória, M. B. A. (2005). Bioactive amines and carbohydrate changes during ripening of 'Prata' banana (*Musa acuminata* × *Musa balbisiana*). *Food Chemistry, 90*, 705–710.

Robinso, J. C. (1996). Distribution and importance; taxonomic classification, cultivars and breeding. In: J. C. Robinson (Ed.), *Banana and plantains* (p. 1–33). Wallingford: CAB International.

Schneeman, B. O. (1987). Soluble and insoluble fiber-different physiological response. *Food Technology, 2*, 81–82.

Selema, M. D., & Farago, M. E. (1996). Trace element concentrations in the fruit peels and trunks of *Musa paradisiaca*. *Phytochemistry, 42*(6), 1523–1525.

Simopoulos, A. P. (1999a). Essential fatty acids in health and chronic disease. *American Journal of Clinical Nutrition, 70*(Suppl. 3), 560S–569S.

Simopoulos, A. P. (1999b). New products from the agri-food industry: the return of $n-3$ fatty acids into the food supply. *Lipids, 34*(Suppl.), S297.

Someya, S., Yoshiki, Y., & Okubo, K. (2002). Antioxidant compounds from bananas (*Musa Cavendish*). *Food Chemistry, 79*, 351–354.

Stover, R. H., & Simmonds, N. W. (1987). Classification of banana cultivars. In R. H. Stover & N. W. Simmonds (Eds.), *Bananas* (3rd ed., pp. 97–103). New york: wiley.

Tchobanoglous, G., Theisen, H., & Vigil, S. (1993). *Integrated solid waste management: engineering principles and management issues*. New York: MCGraw-Hill, p. 3–22.

Terra, N. N., Garcia, E., & Lajolo, F. M. (1983). Starch-sugar transformation during banana ripening: the behaviour of UDP glucose pyrophosphorylase, sucrose synthetase and invertase. *Journal of Food Science, 48*, 1097–1100.

Tewari, H. K., Marwaha, S. S., & Rupal, K. (1986). Ethanol from bananas peels. *Agricultural Wastes, 16*(2), 135–146.

Trease, G. E., Evans, & W. C. A. (1989). *Textbook of pharmacognosy* (13th ed., p. 180–181). Bailliere, Tindall, London.

Valkovic, V. (1978). *Trace elements in petroleum*. Tulsa, OK: Petroleum publishing Co, p. 25–32.

Zhang, P., Whistler, R. L., BeMiller, J. N., & Hamaker, B. R. (2005). Banana starch: production, physicochemical properties, and digestibility – a review. *Carbohydrate Polymers, 59*, 443–458.