Bananas, raw materials for making processed food products

Guylène Aurore, Berthe Parfait, Louis Fahrasmane

ELSEVIER

Trends in Food Science & Technology 20 (2009) 78–91

TRENDS IN FOOD SCIENCE & TECHNOLOGY

Review

Bananas, raw materials for making processed food products

Guylène Aurore[a], Berthe Parfait[b] and Louis Fahrasmane[b,*]

[a]Université des Antilles et de la Guyane, UMR 1270 QUALITROP, F-97 110 Pointe-à-Pitre, France (e-mail: Guylene.Aurore@univ-ag.fr)

[b]INRA, UMR 1270 QUALITROP, Domaine Duclos Prise d'eau F-97 170 Petit-Bourg, France (Tel.: +590 590 25 59 68; fax: +590 590 25 54 15; e-mail: Louis.Fahrasmane@antilles.inra.fr)

Musa spp., comprising banana and plantain, are among the world's leading fruit crops. Worldwide, 103 million tonnes were produced in 2004, according to FAO statistics database. Few bananas produced undergo industrial processing. Plantain and unripe banana are consumed cooked, whereas, mature dessert banana is eaten raw. Characterising bananas, their processed products and processed consumption forms, is a key precondition for objective communication on these foodstuffs. This will enable niche markets for this major crop, undifferentiated product flows of which are in competition on the worldwide market, to be structured on an objective qualitative basis.

Introduction

Banana (*Musa* spp.) cultivation is exclusively tropical (Lassoudière, 2007). Cooked bananas are important portion of food intake for populations in production areas. The dessert banana has a global distribution. Considering the nutrition aspect, it is the world's leading fruit crop, and in terms of economical value it is the number five agricultural crop in world trade. There are nearly 100 banana producing countries. According to the FAO's statistics database (FAOSTAT, 2004), 71 million tonnes of dessert bananas, primarily from the Cavendish subgroup; and 32 million tonnes of plantains were produced in 2004 (Table 1). As well as banana and plantain are among the world's leading fruit crops, there are very few industrial processed products issuing from these tropical productions. In this review, we will focus on the opportunity to develop knowledge on bananas' composition and properties as raw materials for making processed food products.

* Corresponding author.

0924-2244/$ - see front matter
doi:10.1016/j.tifs.2008.10.003

The banana plant, a large, high-biodiversity, fruit-bearing herb

Banana plants are the world's biggest herbs, grown abundantly in many developing countries. They are considered to be one of the most important sources of energy in the diet of people living in tropical humid regions. Banana is a stenothermic plant, cultivated in hot and wet regions, and bear fruit all year round. There are approximately 1200 seedless fleshy fruit varieties. The fruit stalk, or bunch, is the organ of interest for banana cultivation, primarily for food purposes.

The edible fruit cultivars are a man-made complex based on two wild diploid species originating from South-East Asia: *Musa acuminata* Colla (AA), which is highly polymorphous, with spindly plants that grow in clumps, and *Musa balbisiana* Colla (BB), a homogeneous hardy plant with a massive pseudo-trunk. There are diploid, triploid or tetraploid genome groups. The main genome groups are AA, AB, AAA, AAB and ABB. (Bakry *et al.*, 1997; Stover & Simmonds, 1987).

Most dessert banana cultivars in the world are AA or AAA, this last group includes almost all the cultivars sold to export market. Cooking bananas, often named plantains, are mostly AAB, ABB, or BBB. Major cultivars belong to the following subgroups (Table 2):

- Cavendish (AAA) cultivated with intensive farming methods, it is an export dessert type including cultivars: Lacatan, Poyo, Williams, Grande naine, Petite naine,
- Lujugira (AAA) is an East African banana subgroup. Fruits are used cooked or to produce beer, for local markets. Intuntu and mujuba are cultivars in this subgroup. Their production is extensive and optimum between altitude 800 and 1450 m,
- Figue Pomme (AAB) is an acidic dessert subgroup for local markets, extensively produced in tropical areas. Cultivars are Maçà and Silk,

Table 1. World annual production of banana and plantain compared to major fruits and vegetables, according to FAO statistical database for 2004

Worldwide rank	Resource	Latin name	Production in tonnes	Cultivated areas (ha)	Remarks
1	Sugarcane	*Saccharum* spp.	1 393 951 980	20 287 184	76% of the world sugar production are from sugarcane
2	Maize	*Zea mays*	721 379 361	147 022 333	Cereal: food and feed, starch, milling
3	Wheat	*Triticum*	627 130 584	215 765 044	Cereal: food and feed, milling
4	Rice	*Oryza*	605 758 530	151 295 524	Cereal: food and beverages
5	Potato	*Solanum tuberosum*	327 624 417	18 630 196	Tuber
8	Cassava	*Manihot esculenta*	202 648 218	18 511 889	Tropical root
11	Sweet potato	*Ipomea batatas*	127 139 553	8 618 866	Tropical tuber
12	Tomato	*Lycopersicon esculentum*	120 384 017	4 421 734	2nd vegetable produced: 30% processed
15	**Banana**	***Musa* spp.**	**71 343 413**	**4 446 044**	**Tropical production consumed raw**
17	Grape	*Vitis vinifera*	66 569 761	7 586 595	For table, wine production, dried, …
18	Orange	*Citrus sinensis*	62 814 424	3 601 459	Consumed raw or processed
19	Apple	*Malus domestica*	61 919 066	5 178 360	Consumed raw, processed
27	**Plantain**	***Musa* spp.**	**32 592 554**	**5 203 812**	**Vegetable. Tropical production**

Table 2. Main cultivars of banana and plantain (cooking banana), according to data from: Bakry *et al.* (1997); Nakasone and Paull (1999); Rieger (2006)

Group	Subgroup	Cultivar	Fruit usage	Geographic distribution
AA	Sucrier	Frayssinette Figue sucrée	Sweet dessert	All continents
	Pisang Lilin		Dessert	Indonesia, Malaysia
	Pisang Berangan		Dessert	
	Lakatan		Dessert	
AAA	Gros Michel	Gros Michel	Dessert	All continents
	Cavendish	Lacatan, Poyo, Grand Nain Williams Petite Naine	Dessert	Exporter countries
	Figue rose	Figue rose	Dessert	
	Lujugira	Intuntu	Cooking, Beer	East Afric. highland
		Mujuba	Cooking, Beer	
AAAA	Champa Nasik		Dessert	
AAAB	Goldfinger	Goldfinger	Dessert	America, Australia
AB	Ney Poovan	Safet Velchi,	Dessert acid	India, East Africa
		Sukari	Dessert acid	
AAB	Figue Pomme	Maçà, Silk	Dessert acid	All continents
	Pome	Prata	Dessert acid	Brazil, India,
	Mysore			India
	Plantain	French, Horn	Cooking	Africa, Carribean
		Corne	Cooking	
ABB	Bluggoe	Bluggoe	Cooking	Philippines, America
	Poteau		Cooking	
	Pisang Awak	Fougamou	Dessert	
ABBB		Klue Terapod	Cooking	
BBB	Saba	Saba	Cooking	Indonesia, Malaysia

- Plantain (AAB) is a cooking banana subgroup for local food markets; extensively produced in Africa, the Caribbean and Latin America. French, Corn and faux Corn are some of the cultivars,
- Saba Bluggoe (ABB) is a cooking banana type, for local food markets and processing industries, in Philippines, the Caribbean, and Latin America,
- Sucrier (AA) subgroup includes Frayssinnette cultivar, fruits produced are small, very sweet and thin-skinned.

The great biodiversity of banana plants provides potential for varietal creation, for the purpose of promoting characteristics compatible with food expectations, in terms of modern consumer health concern, and new uses of fruits as a raw material for food and feed processing…

Harnessing banana plant biodiversity

The creation of disease and pest-resistant varieties is a priority for genetic improvement programmes. This is readily comprehensible in tropical environment, where parasite pressure is exacerbated. Cultivation parameters (such as early production, productivity, wind resistance and fruit conformity) are secondary objectives. Banana plant cultivation for local consumption harnesses a multitude of cultivars suited to different farming situations and uses. Dessert banana cultivars grown for export are also known as "commercial bananas". Western tables most commonly contain the Lacatan, Poyo and Grande naine cultivars.

The great biodiversity of banana plants is an asset in any programme that aims to develop fruit organoleptic and nutritional quality including macroconstituents, their flavour, and antioxidant content. Physiological mechanisms involved in developing quality and identification of molecular markers, associated by a candidate gene approach, are areas for investigation to understand and improve banana quality.

The concern to develop solutions for new consumer demands is a driving force behind improving knowledge of fruit and vegetable quality potential and of the mechanisms for developing it, in the hope of using these crops in a variety of product forms (fresh, bioactive molecules, processed products). The options for consumers need to be diversified, and new commercial niches need to be found, to enable better use of production.

There is a growing interest in developing knowledge of bananas' antioxidant composition (Davey *et al.*, 2007; Kondo, Kittikorn, & Kanlayanarat, 2005; Verde Mendez *et al.*, 2003). Some cooking cultivars are rich in carotenoids: 5000 μg/100 g equivalent carotene are found in an orange coloured Micronesian cultivar (Englberger, 2003). Dopamine and vitamin C contents in bananas are claimed to give them a high antioxidant capacity (Kanazawa & Sakakibara, 2000). According to Someya, Yoshiki, and Okubo (2002) bananas (*Musa Cavendish*) should be considered to be a good source of natural antioxidants for food.

Cultivation, harvesting and post-harvest treatments

A period of about 8–13 months exists between planting the banana tree and harvesting bunches, which can contain 100–400 fruits. Optimum harvest date, or flowering-harvest interval, is determined from flowering, according to the climate zone and variety. It takes into account the fruit size: length and grade, which is the diameter measured in the middle part perpendicular to the plane of the fruit's curve. Banana fruits are climacteric, i.e. the transition from end of development to product fresh consumption state is accompanied by intense respiratory activity and production of ethylene. Applying a controlled atmosphere with a supply of exogenous ethylene, combined with appropriate temperature and moisture control, enables ripening to be managed with precision, at the chosen time, a few weeks after harvesting. Ripening determines the essential appearance and taste qualities of dessert bananas when consumed fresh (bright yellow-coloured skin, flavours, consistency of pulp and starch–sugar transition). Ethylene is used as a catalyst for

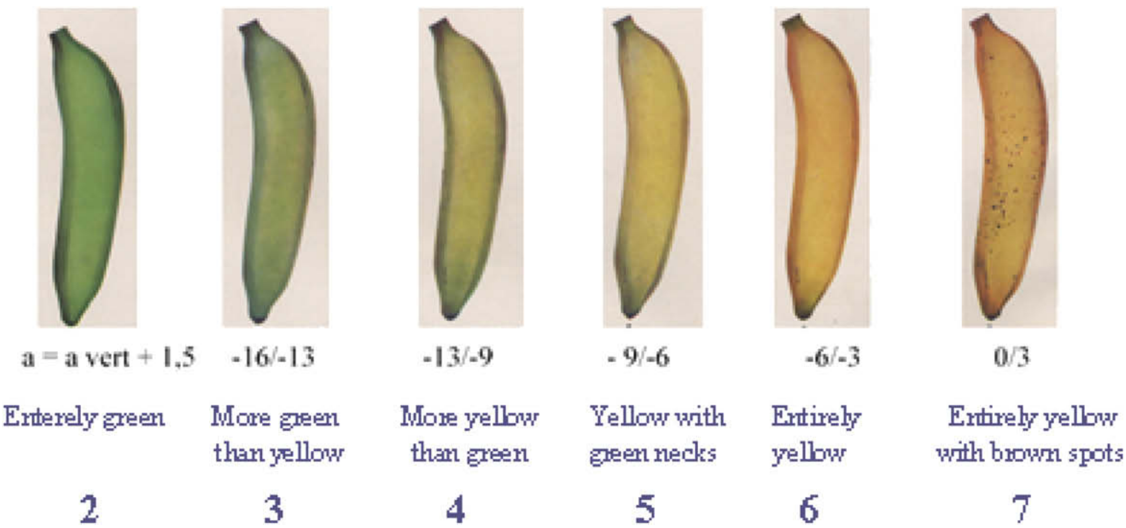

Fig. 1. Colour index according to the commercial peel colour scale.

triggering climacteric change. The fruit is then delivered for consumption. The ripening classification defines 8 stages by colour index (Fig. 1). At stages 1–3, banana is not usually eaten like fruit, because it is green, very hard, astringent, and rich in starch. At stage 8, banana is overripe and muddy.

Bunches can be harvested mature-green, i.e. well developed, mature but still green. The fruit will then be ripened, either naturally at ambient temperature, or artificially in a controlled atmosphere chamber.

For export, the harvesting time and post-harvest conditions need to be managed, so as to maintain a fairly long ''green life'', which can extend up to 60 days for Cavendish bananas (Bugaud, Chillet, Beauté, & Dubois, 2006). During transport by ship, which may be for several days or 2–3 weeks, fruit is maintained at 14 °C, the physiological temperature threshold below which fruit growth and change will cease (Lassoudière, 2007). An atmosphere of 5–6.5% O_2 and 5–6% CO_2 is provided, in addition to controlled moisture. The naturally released ethylene also needs to be eliminated or trapped (Laville, 1994).

Exposing green fruit to excessive temperatures, over 35 °C, irreversibly undermines the banana ripening and yellowing processes (Laville, 1994).

Cooking bananas keeps well for nearly 60 days at 9 or 10 °C, in a partially evacuated polyethylene bag.

When bananas are aimed at the local market, the harvest can be much later than for exported bananas, and maturation can begin even before harvesting.

Banana production and worldwide trade

There are two main distinct modes of production:

- Firstly, an industrial single-cropping, without rotation, which employs many inputs, producing for export. Banana plants' ratio is 900–2000 individuals per hectare. Fruit yields may reach 50–70 tonnes/ha. Export bananas are derived from a highly technical production process, which requires perfect control of the cultivation calendar, so as to harvest the fruit at the optimum stage of maturity, before it passes the green-yellow stage.
- Secondly, a multi-cropping system that grows many different cultivars, which are suited to different cultivation situations. Production systems make little or no use of inputs and pesticides. Production is for local markets. Yields are low, generally reaching 6–15 tonnes/ha for the plantain (Bakry *et al*., 1997).

The dessert banana is ahead of the grape and orange (Table 1). However, less than 20% of dessert banana production is traded internationally, the value of which is estimated at over 7 billion euros. India, Brazil, Ecuador, the Philippines, China and Indonesia share 55% of overall world production, but India and Brazil have practically no involvement in world trade.

With 13 million tonnes/year, dessert banana is the world's most exported fruit. In terms of value, it is the fifth most important agricultural crop in world trade, after coffee, cereals, sugar and cacao. North America, Europe and Japan are the main importers. Marketing and pricing of bananas imported into Europe have since 1993 been ruled by a Common Market Organisation for Bananas (CMOB), which covers the flows from various zones: Europe, ACP countries, Latin America (dollar bananas) and the Philippines. The considerable socio-economic challenges existing in some producing countries and the removal of preferential trading arrangements with EU, have lead to tension and recourse to WTO arbitration (World Trade Organisation).

Competition between exporters of dessert bananas from different producer countries makes commercial quality of the products a critical marketing factor. High quality products are obtained under highly controlled technical conditions (Marchal, 1993). Product identification and labelling signs have been set up to ensure product quality and origin, create added value, and enable consumers to distinguish products with particular and specific qualities. During the past few years new regulations have appeared in Europe:

- *''Agriculture Raisonnée''* certification [Rational agriculture],
- the AB label (organic farming). The Dominican Republic is the main supplier of organic bananas. AB bananas represent a low percentage of world trade,
- Fairtrade, which includes among others the labels Max Havelaar, Ecocert. These are 'ethical products'. The International Fairtrade Labelling Organisation (FLO) coordinates adherence to the standards governing the title internationally (Murray & Raynolds, 2000; Piraux, 2006; Shreck, 2005).

Equivalent standards have been developed in Central and South America, particularly SAN (*Sustainable agriculture network*) and SA8000 (*Social Accountability*).

Consumption of bananas and their processed products

Bananas are among the world's leading food crops, after rice, wheat and maize (Table 1). Almost ninety percent of production is consumed in the production areas, especially in the poorest countries in Africa, Latin America and Asia. In certain regions, pureed banana is the first solid food given to infants. Annual consumption may be as much as 250 kg per capita in East Africa. Bananas contribute to reducing food insecurity in producer country populations. Their composition, which includes a high carbohydrate content (Table 3), makes them a staple calorie resource for over 500 million inhabitants of tropical countries.

General characteristics of banana consumption

In culinary terms, banana cultivars can be divided into two main groups: sweet or dessert bananas, and cooking bananas, including the plantain (Champion, 1963; Lescot,

Table 3. Chemical composition and biochemical features of banana and plantain at different physiological stages, and after transformation, per 100 g of fresh weight

Component or parameter	Unit	Sweet banana pulp				Plantain pulp	
		Ripe[a]	Unripe[b]	Dried[a]	Dehydrated or flour[a]	Unripe[c]	Ripe
Energy	Kcal	89	110[b]	257	340	91	122[e]
Water	g	74	69[b]	28	3.0	63	65[e]
Protein	g	1.1	1.4[b]	3.0	3.9	0.8	1.3[e]
Total lipid	g	0.3	0.2[b]	1.0	1.8	0.1	0.37[e]
Carbohydrate	g	21.8	28.7[b]	63.0	82.1	24.3	32[e]
Dietary fibre	g	2.0	0.5[b]	5.5	7.6	5.4	2.0–3.4[e]
Na	mg	1.0		8.0	3.0		4.0[e]
K	mg	385.0		1150.0	1491.0		500[e]
Ca	mg	8.0	8[b]	20.0	22.0	7	3.0[e]
Mg	mg	30		90.0	108.0	33	35.0[e]
P	mg	22		75.0	74.0	35	30.0[e]
Fe	mg	0.42	0.9[b]	1.3	1.15	0.5	0.6[e]
Cu	mg	0.11		0.4	0.39	0.16	
Zn	mg	0.18		0.5	0.61	0.1	
Mn	mg	0.2			0.57	15	
Eq. β-carotene	μg	68.0	48.3[b]	150.0	183.0	0.03–1.20	390–1035[d]
Vitamin E	mg	0.29		0.6		–	
Vitamin C	mg	11.7	31[b]	4.0		20	20[d]
Thiamin	mg	0.04	0.04[b]	0.1	0.18	0.05	0.08[d]
Riboflavin	mg	0.07	0.02[b]	0.18	0.24	0.05	0.04[d]
Niacin	mg	0.61	0.6[b]	2.0	2.8	0.7	0.6[d]
Panthotenic acid	mg	0.28				0.37	
Vitamin B6	mg	0.47				–	
Total Folate	μg	23.0				0.016	
Biotin	μg	2.6				–	
Isoleucine	mg	34.0			167.0		
Leucine	mg	71.0			359.0		
Lysine	mg	50.0			162.0		
Methionine	mg	14.0			74.0		
Cystine	mg	20.0			63.0		
Phenylalanine	mg	41.0			201.0		
Tyrosine	mg	26.0			121.0		
Threonine	mg	36.0			171.0		
Tryptophan	mg	13.0					
Valine	mg	49.0			282.0		
Arginine	mg	57.0			176.0		
Histidine	mg	86.0			333.0		
Alanine	mg	43.0			222.0		
Aspartic acid	mg	120.0			503.0		
Glutamic Acid	mg	115.0			399.0		
Glycine	mg	41.0			190.0		
Proline	mg	43.0			229.0		
Serine	mg	49.0			226.0		
Dopamine	mg	65.0					
Serotonine	mg	3.3				45[c]	76[c]
Thiamine	mg	0.7					
Malic acid	meq	6.20[c]	1.36[c]				
Citric acid	meq	2.17[c]	0.68[c]				
Oxalic acid	meq	1.37[c]	2.33[c]				
Other acids	meq	0.17[c]	0.19[c]				

[a] CIQUAL – CNEVA (1993).
[b] Anonymous (1981).
[c] Marriott and Lancaster (1983).
[d] Woolfe (1992).
[e] Lassoudière (2007).

1990; Marchal, 1993; Marriott & Lancaster, 1983; Nakasone & Paull, 1999; Turner, 1994).

In terms of use and consumption, bananas are:

- a basic foodstuff consumed fresh or cooked. The mature dessert banana is primarily consumed in its natural state, raw. Unripe, it is cooked prior to consumption. Green or ripe, they represent an important part of basic alimentation for significant population groups in producer countries.
- raw materials in a variety of domestic and regional products (Adams, 1980; Akubor, Obio, Nwadomere, & Obiomah, 2003; Carreño & Aristizàbal, 2003; Davies, 1993; Guerrero, Alzamora, & Gerschenson, 1994; Hammond, Egg, Diggins, & Coble, 1996): whole, peeled and dried bananas; cooked bananas (boiled, crisps, fried, purée); domestic preparations (fritters, jams, wines, beer); domestic and artisanal flour; green banana starch; purée; alcohol; regional beers; wine; vinegar; nectar; chunks and purees as ingredients in culinary preparations (pastries, desserts, ice-creams, sorbets and cream products). Very few of these products are found in the occidental mass market type, showing importance and consumption forms comparable to products from orange and apple.
- an energy source for athletes: The concept of banana products suited for sports applications has recently been harnessed by a food processor, in the production of energizing drinks and dried banana bars for athletes. Its energy value, in combination with vitamins and minerals (K, Mg) prevents muscular contractions (Roubert, 2005).
- livestock feed. Unpeeled green bananas are used as an animal feed, especially for pigs.

Industrial processing of bananas is under-developed.

Better use of bananas and plantain could be achieved by investigating their suitability for different types of processing. Innovations will be possible on the basis of improved knowledge of the varieties, their composition, the agro-pedoclimatic cultivation conditions and their effects on quality of the physiological stages of treatment and harvesting, as well as technological abilities.

The dessert banana

Its edible part is pulpy, firm to tender, free from seeds or pips, and has a characteristic flavour. It is protected by a peel which, under normal temperature and pressure conditions, ensures perfect food safety, while upon maturity leaves it flexible enough to be detached from the pulp without using any implement. At maturity, skin of the fresh fruit changes from green to yellow (Fig. 1; Salvador, Sanz, & Fiszman, 2006). The skin can be manually detached from the edible pulp, even by a child that can feed itself, and leaves no soiling marks on the consumer. The ease and cleanliness of eating a ripe banana are unique, and certainly contributes to its success (Baldry, Coursey, & Howard, 1981).

Dessert banana pulp and its macroconstituents

Pulp is firm when the fruit is not ripe, but softens during maturation, so that a puree may be obtained simply by mashing with a fork (Kajuna, Bilanski, & Mittal, 1997). This pulp, comprising 75% water, is among the most calorie-rich (with 90 kcal/100 g) of non-oil fresh fruits. It contains approximately 20 g of carbohydrates in total per 100 g of fresh pulp, out of which fibre 2 g per 100 g fresh weight is useful for regulation of intestinal transit. Potassium is the most abundant mineral with estimated values in the range of 4.10–5.55 mg per 100 g dry weight (Goswami & Borthakur, 1996). Ripe banana is an excellent food for effort, because its pulp is sugar-rich and easily digested, and its content in potassium and magnesium is interesting for muscle contraction control (Table 3).

Starch is the main form of carbon storage in unripe bananas. Amylases enable transformation of starch into sugars during maturation by depolymerisation of the α-glucan chains, which are broken by endo-hydrolytic enzymes (Oliveira do Nascimento *et al*., 2006). Starch in the green fruit is converted into sugars (sucrose, glucose, fructose and in very small quantities maltose and rhamnose), the percentage of which rises from 1 or 2% to nearly 20% by the end of ripening. Total soluble solid contents in banana increase with fruit ripening development (Bugaud *et al*., 2006).

In the past thirty years, many studies have been published about green banana pulp, flour production from different banana varieties, some structural, physicochemical and functional properties of the starch, its digestibility and flavour. It is produced from large quantities of rejects in the export industry. Such rejects consist of below-grade fruit and/or fruit with skin appearance defects, and generally represents 20% of the harvest. There have also been studies into nutritional and non-food properties, as well as banana flour (dried meal) and starch extraction and use from such fruit. Zhang, Whistler, BeMiller, and Hamaker (2005) reviewed banana starch and prospects for improving knowledge of its molecular architecture. Banana starch is evaluated for its use in generating resistant starch (RS) type III (Lehmann, Jacobasch, & Schmiedl, 2002). It shows a mixture between A and B type X-ray diffraction pattern. It has a high temperature (77.6 °C) and high enthalpy (23.4 J/g) of gelatinization in excess water conditions (Millan-Testa, Mendez-Montealvo, Ottenhof, Farhat, & Bello-Pérez, 2005). Banana starch is apparently at least as functional as maize starch, with good potential acceptability because of its lack of flavour, while being relatively different from starches of other plants. There are limited scale uses, as an ingredient (yoghurt, ketchup); substitution of banana flour, in certain proportions, to wheat flour is used in baking and pastry-making preparations (Juarez-Garcia, Agama-Acevedo, Sayago-Ayerdi, Rodriguez-Ambriz, &

Bello-Pérez, 2006). Noodles, a preparation containing the plantain starch, exhibited a limited digestibility due to their relatively high resistant starch content and a moderate *in vitro* predicted glycemic index (Osorio-Diaz *et al*., 2008). Currently there is no real industrial banana flour or starch based production, even for animal feed.

Starch modifications by physical and chemical actions, as well as its rheological behaviour, were investigated by Bello-Pérez, Agama-Acevedo, Sanchez-Hernandez, and Paredez-Lopez (1999); Juarez-Garcia *et al*. (2006); da Mota, Lajolo, Ciacco, and Cordenunsi (2000); Nimsung, Thongngam, and Naivikul (2007); Nuñez-Santiago, Bello-Pérez, and Tecante (2004); Oliveira do Nascimento *et al*. (2006); Siriwong, Tulyathan, and Waiprib (2003); de la Torre-Gutiérrez, Chel-Guerrero, and Betancur-Ancona (2008); Waliszewski, Aparicio, Bello, and Monroy (2003). These studies indicated that banana starch is suitable for food applications that require high amylose and high retrogradation. But it is inappropriate, however, for use in refrigerated or frozen products. Chemical modification of banana starch produced improvement in those properties. Starch isolated from unripe banana (*M. balbisiana*) had high syneresis and low stability in refrigeration and freezing cycles. Given its properties, banana starch has potential applications in food systems requiring high temperature processing, such as jellies, sausages, bakery and canned products. Phosphorylated and hydroxypropylated banana starches showed improvement in clarity and phosphated starch has shown the best freeze–thaw stability. About banana flour, considering that the flour production is easier and faster than the isolation of the starch, it would be not only more practical but also less expensive to use the flour. Experimental bread was formulated with banana flour and the product was studied regarding chemical composition, available starch, resistant starch and rate of starch digestion *in vitro*. Of the total starch of the banana flour, available starch was 56% and resistant starch 17%. These results suggested a "slow carbohydrate" feature for the banana flour-based products. Banana flour is a potential ingredient for bakery products containing slowly digestible carbohydrates.

Microconstituents in dessert banana pulp

The banana peel contains flavonoïds and catecholamines. The banana pulp contains cathecholamines. The amount of these compounds was determined in both peel and pulp at the various ripening stages (Kanazawa & Sakakibara, 2000). Banana contains a large amount of dopamine in both peel and pulp. The amount decreases with ripening and remains at level between 80 and 560 mg per 100 g of peel and between 2.5 and 10 mg per 100 g of pulp (Kanazawa & Sakakibara, 2000). During the later stages of the ripening, the level of salsolinol, norepinephrine and epinephrine increases. Dopamine plays important roles as neurotransmitter and precursor for norepinephrine and epinephrine (Sojo, Nunez-Delicado, Sanchez-Ferrer, & Garcia-Carmona, 2000). Banana pulp can oxidize salsolinol. An activation of dopamine oxidation was found in the presence of salsolinol. Dopamine has been found to protect against intestinal mucosal injury (MacNaughton & Wallace, 1989). Recent epidemiological studies suggest that flavonoid-rich diets reduce the risk of cardiovascular disease (Hertog, Feskens, Hollman, Katan, & Kromhout, 1993), diabetes, cancer and neurodegenerative diseases (Salvatore *et al*., 2005).

Bananas are identified as relatively rich in pyridoxine (vit. B6) (Leklem, 1999). There is some evidence that pyridoxine protects against cancer of the oesophagus (World Cancer Research Fund International, 2007). Most compositional research has been done with the export Cavendish subgroup cultivars. Pulp of these cultivars has a phenolic compound content of around 30–60 mg/100 g fresh matter (Verde Mendez *et al*., 2003). These phenolic compounds are present in greater quantity in skin than in pulp. Fruit contains lutein, α- and β-carotene (van den Berg *et al*., 2000) and relatively high concentrations of catecholamine and dopamine, a powerful antioxidant, as well as norepinephrine, gallocatechin, naringenin-7-O-neohesperidoside (Crozier *et al*., 2006; Tramil, 1999).

Acidity of bananas pulp decreases from pH 5 in the preclimacteric phase to pH 4.2 in the final phase. As for micronutrients (Table 3), at maturity bananas are relatively rich in vitamins A (carotene), B (thiamine, riboflavin, niacin, B6) and C (ascorbic acid), and in potassium, phosphorus and magnesium. The content of phenolic compounds responsible for astringency of green bananas decreases with ripening (Kanazawa & Sakakibara, 2000).

Aroma and aromatic constituents in dessert banana

Aromatic properties (Boudhrioua, Giampaoli, & Bonazzi, 2003; Pérez, Cert, Rios, & Olias, 1997) of the banana and/or its texture make it a valued ingredient in culinary preparations, pastries and cream products (banana flambée, banana split). Natural banana oil is highly volatile. Many studies have been performed only on fresh dessert banana (*M. acuminata*, *Musa sapientum*, *M. Cavendish*) about their aromatic components. Nevertheless, there is no information about the volatile compounds of cooking bananas. From the literature survey, more than 40 compounds were identified but 12 volatile compounds characterize banana aroma (5 acetates, 4 butyrates and 3 alcohols) (Cosio & René, 1996; Macku & Jennings, 1987; Maltini & Giangiacomo, 1976; Marriott, 1980; Mattei, 1973; Pérez *et al*., 1997). These compounds are used as indicators of aromatic quality of dessert banana *M. Cavendish* (Cosio & René, 1996). The composition of banana fruit volatile compounds is a complex mixture of several chemical classes, for all the studied varieties from Ivory Coast (Cosio & René, 1996), from Madeira (Nogueira, Fernandes, & Nascimento, 2003), and from Honduras (Jordan, Tandon, Shaw, & Goodner, 2001). Many of volatile compounds of banana, such as esters and alcohols, play an important role in the aromatic properties of dessert bananas. The ester fraction contributes to fruity note (Pérez *et al.*, 1997). The 3-methyl-butyl-butanoate is the predominant ester (15.8–20.5 mg/kg fresh fruit) (Nogueira *et al.*, 2003). The octyl acetate is the minor component (1.6–3.2 mg/kg fresh fruit). The most important alcohol is ethanol (23.9 mg/kg fresh fruit). Other fractions, such as carbonyl compounds, carboxylic acids are associated with the aroma banana. The carboxylic acids are associated with the ripened aroma. The carbonyl fraction contributes, with the alcohols, to the woody or musty flavour. Hex-2(E)-enal and pentan-2-one are the major components of this fraction which contribute to the herbal note (Schiota, 1993).

Phenylpropanoids such as eugenol, methyl eugenol and elimicin are also found in the banana fruit but at very low concentration (<1 mg/kg fresh fruit) (Jordan *et al.*, 2001). They contribute to the floral note of the ripening aroma (Macku & Jennings, 1987).

Aromatic changes of bananas from Canary Islands and Ivory Coast were studied during ripening and air-drying (Boudhrioua *et al.*, 2003). A continuous decrease was observed for the isoamyl acetate, isoamyl alcohol and butyl acetate whereas some compounds increase or seem to be formed at the end of drying. Elimicin is the most thermal resistant compound.

Glycosidically bound volatile compounds from two banana cultivars from Costa Rica and Canary Islands were studied (Pérez *et al.*, 1997). 35 Aglycons were found: alcohols such as decan-1-ol and 2-phenylethanol; acids such as 3-methylbutanoïc, benzoic acid are quantitatively the most important aglycons in glycosides isolated from fresh fruit banana.

Cooking bananas

Plantain banana, and more generally cooking bananas, is not described as well as dessert banana (Idachaba & Onyezili, 1994; de la Torre-Gutiérrez *et al.*, 2008). Overall they are as rich in carbohydrates as the dessert banana (Table 3), firmer and less valued as a fresh product even when mature, as they still contain starch at this stage (Valmayor, 2000). They are consumed necessarily cooked, whether green or ripe. They are also a raw material for domestic and artisanal production of flour, crisps, beer and wine (Akubor *et al.*, 2003; Carreňo & Aristizàbal, 2003; Lemaire, Reynes, Tchango Tchango, Ngalani, & Guillaumont, 1997). Yield per hectare of plantain bananas varies considerably between countries: 1.95 tonnes/ha in Tanzania to 50.9 tonnes/ha in Belize (FAOSTAT, 2004; Lescot, 1997).

The plantain banana is much less prone to browning than the dessert banana (Ngalani, Signoret, & Crouzet, 1993; Yang *et al.*, 2004). It can be cooked without manifesting the Maillard reaction, and retains a stable orange colour.

Industrialised processing

In spite of its leading role in trade, and its importance in the diet of certain tropical populations, banana, like certain other tropical crops such as sweet potato and manioc, does not undergo industrialised processing comparable to that of other fruits and vegetables grown outside tropical zones, such as the tomato, orange, apple and potato, whose production in term of quantities is of the same order (Tables 1 and 4). It is opportune to develop processed products tailored to modern consumer expectations, providing a greater variety and convenience of uses, by making products which can be used in other products' formulation.

According to Espiard (2002), on the eve of 2000, industrial processing of the dessert banana "only involved one thousandth of the bananas produced worldwide". There is progress to be made for quality products. Bananas represent a potential raw materials for food and non-food processing industries:

- Ripe bananas can be considered for industrial processing leading to types of products comparable to those obtained from apples: juice, fruit drinks, fermented drinks, stewed fruit, puree, marmalade, jam, flakes, confectionery and pastry ingredients, sorbets and ice-creams.
- Green or unripe bananas can be considered as a resource for production of modern forms of consumption: snacks (Lemaire *et al.*, 1997), processed and pre-cooked products.

Existing processings on a domestic, artisanal and regional scale may be sources of inspiration for development of industrial productions, comparable to those involving apple and orange. The processing industries of banana and plantain into chips, flour, dried pulps, jam, spirits distilled from wine or beer,… are growing slowly in banana producer countries, meanwhile the important volume of peel generated is source of interest and cannot be regarded as "waste" (Happi Emaga, Herinavalona Andrianaivo, Wathelet, Tchango Tchango, & Paquot, 2007; Enwefa, 1991).

At present, flavour of dessert banana is the property that seems to be most valued among supermarket processed products. Indeed, bananas and derived products are minor ingredients, generally under 30%, in various preparations sold in modern distribution circuits: breakfasts combining dried fruits, stewed fruit desserts where apples are often predominant, nibbles and baby foods. Banana flavour is reproduced with short fatty acid amylic esters, including butyric ester to provide a fruity note.

Production of flour, dried bananas, whole or as crisps, is under development. The lack of automatic peeling devices limits development of these processed products for SMEs. Banana crisps and jam are appearing in supermarkets.

In the manufacture of Alcohol-Free Drinks, the pulpy nature of banana does not enable juice production simply by means of pressing. Pulp is used for preparing cordials. In 2004 a patent, FR 02-06545, was published on pure banana juice production.

The scientific and technologic literature describes many innovative laboratory studies of bananas treatments and processed products qualities. Very often, industrial productions involving the results of these studies are not still exploited:

Table 4. Composition and some characteristic parameters of fresh banana, plantain and fruits having comparable transformation potentialities, at maturity (per 100 g of edible portion)

Constituents and parameters	Unit	Orange[b] *Citrus sinensis*	Apple[c] *Malus domestica*	Banana[b] *Musa* spp.	Plantain *Musa* spp.	Potato *Solanum tuberosum*	Sweet potato' *Ipomea batatas*
Energy	Kcal	42	52	89.0	122[e]	80	111
Water	g	86.6	84	74.0	65.0[e]	78	70
Protein	g	1.0	0.3	1.1	1.3[e]	2.1	1.5
Total lipid	g	0.2	0.35	0.3	0.37[e]	0.1	0.3
Carbohydrate	g	8.8	12	21.8	32[e]	18.5	26.1
Fibre	g	1.8	0.8	2.0	2.0–3.4[e]	2.1[b]	1.2–2.62
Sodium	mg	Tr	2	1.0	4.0[e]	0.8[b]	21
Potassium	mg	179.0	120	385.0	500.0[e]	410[b]	396
Calcium	mg	40.0	6	8.0	3.0[e]	14[b]	24
Magnesium	mg	10.0	5	30.0	35.0[e]	27[b]	20
Iron	mg	0.12	0.4	0.40	0.6[e]	0.8	0.69
Copper	mg	0.05	0.08	0.11		0.16[b]	0.16
Zinc	mg	0.07		0.19			0.24
Manganese	mg	0.03	10.05	0.2		0.17[b]	0.24
Phosphorus	mg	16.0	11	22.0	30.0[e]	52[b]	41
Eq. Bcarotène	µg	1 200		68.0	390–1 035[d]	0–Tr	0–20 000
Vitamin C (Ascorbic acid)	mg	53	3–30	11.7	20[d]	30	23.6
Thiamin (vit. B1)	µg	90	10–100	40	80[d]	110	90
Riboflavin (vit. B2)	µg	40	50	70	40[d]	40	30
Niacin (vit. PP)	µg	280	100–500	610	600[d]	1200	600
Panthotenic acid(vit. B5)	µg	300	200	280		300	590
Pyridoxine (vit. B6)	µg	60	100	470		250	260
Folic acid	µg	30.0		23.0		24	14
Yield in pulp, pulpous juice or flesh[f]	%	65-88	86–89	57–60			88
Global culture yield	Tonne ha^{-1}	17.4[a]	11.9[a]	16.0[a]	6.2[a]	17.6[a]	17.7[a]
Global production	Tonne	62 814 424[a]	61 919 066[a]	71 343 413[a]	32 592 554[a]	327 624 417[a]	127 139 553[a]

[a] FAO database for 2004.
[b] CIQUAL – CNEVA (1993).
[d] Woolfe (1992).
[c] Table Geigy, cited in Belou (1988). Les délices du potager. Editons Vie & Santé. France.
[e] Lassoudière (2007).
[f] Espiard (2002).

- Solar drying of bananas' modelization (Phoungchandang & Woods, 2000),
- Banana flour as a potential ingredient for bakery products containing slowly digestible carbohydrate (Juarez-Garcia et *al*., 2006),
- Ultrasonic pre-treatment for drying is interesting when large amount of water needs to be removed from the fruit (Fernandes & Rodriges, 2007),
- Cookies production substituting a proportion of wheat flour for unripe banana (Fasolin, de Almeida, Castanho, & Netto-Oliveira, 2007); and their digestibility study (Aparicio-Saguilàn *et al*., 2007),
- Production of spray dried banana powder and the effects of packaging and the storage on the product properties (Evelin, Jacob, & Vijayanand, 2007),
- Production of fibre-rich powder by the acid treatment of unripe banana flour may be important for the development of food and medical products (Aguirre-Cruz, Alvarez-Castillo, Yee-Madeira, & Bello-Pérez, 2008),
- Partial characterisation of fructose syrup obtained from plantain starch (Hernandez-Uribe, Rodrigez-Ambriz, & Bello-Pérez, 2008),
- Effect of processing technique in the improvement of energy content and nutrient availability of weaning foods from cooking banana (Bukusuba, Muranga, & Nampala, 2008)…

Prospects for research and developments in bananas

In our general context it is important to elaborate new knowledge about bananas, and identify unknown features, to improve their consumption and their processed products.

The growing proportion of processed products in human diet has put the agri-business sector in an important situation of responsibility in terms of public health. Technological development and innovation have considerably increased food safety, food hygiene and products shelf life. However, certain industrial processes and consumption practices degrade and/or eliminate certain functional nutrients and health-promoting compounds contained in fresh products. Progress in food science has provided a better understanding of the effects of food functional quality, in public well-being, which can be assessed in particular *via* morbidity related to so-called "civilisation" degenerative pathologies. Worldwide there is an increasing demand for foods showing traditional nutritional aspects whereas health benefits are expected from its regular ingestion (Heo *et al*., 2008).

Highlighting the impact of diet on preventing a significant number of modern pathologies has led to nutritional messages being issued as part of public health policies. In modern societies, erosion of convivial dietary models, including the family, and the shift of a number of individual-level choices, have contributed to development of individual demand for advice in terms of preventive diet. One response by producers and food processors, is the production of *health foods*, which are not medicines, and therefore not supposed to be cures: these *health foods* are accompanied by health-promoting claims that may or may not have been justified by the appropriate research.

Alongside health-promoting claims, there are new challenges emerging for plant resource functional properties, namely:

- Consumer information on foodstuff contents of substances or ingredients with an established preventive impact on pathologies and/or nutritional benefit. In terms of human nutrition, the relationship between diet and health has become a major challenge, since cross-cultural epidemiological studies have shown, at population level, that fruit and vegetable consumption has a preventive effect on certain pathologies, the action mechanisms of which are largely unknown (Apfelbaum, Romon, & Dubus, 2004; Joffe & Robertson, 2001). At an individual level, this effect can only be stated in terms of probability, since there are intervening uncontrollable individual factors, such as specific genetic heritage.
- Maximum preservation of nutritional and functional properties, by involving technologies and/or processes not degrading useful ingredients, such as new soft technologies that use very high pressures, light flashes, pulsed electric fields (Bimbenet & Trystram, 2005; Fernandes & Rodriges, 2007; Haxaire, 2001).

Bananas are used in special diets where ease of digestibility, low fat, minerals and vitamin content are required. These special diets are used for babies, the elderly and patients with stomach problems, gout, and arthritis (Nakasone & Paull, 1999). Green bananas possess antidiarrheal action (Rabbani *et al*., 2004). It is traditionally used to cure intestinal disorders (Aurora & Sharma, 1990).

How could the food processing sector preserve, or even improve, the functional properties of foodstuffs? It should take greater consideration than before of the physiological stages of harvesting, and post-harvest treatment processes of fruits and vegetables, for a better understanding of the dynamics of useful compounds. Investigating the variation factors of plant resource composition, and the interactions between the various constituents, will be a source of knowledge for the choice and control of processing operations. It is very important for dessert banana harvested at a green stage, for exportation.

Co-products and by-products of fruits and vegetables are available in large quantities, yet are not generally used for processing, though they may be rich in biologically active substances. What are the best ways to extract and use these substances? Some authors have established banana peels as an energy-rich carbohydrate substrate for the development of microbial protein for food and feed applications (Chung & Meyers, 1978; Enwefa, 1991). For Someya *et al.* (2002) banana peel should also be considered to be a functional food source against cancer and heart disease, since the banana peel is rich in gallocatechin. It is important to pay special attention to pesticides residues in extracts from banana peel, coming from commercial cultivations.

A systematic review of scientific literature indicates that consumption of fruits, vegetables and foods containing dietary fibres probably protects against certain cancers (World Cancer Research Fund International, 2007). Research has been initiated in various places into fruits, vegetables, cereals, spices and condiments to obtain a better understanding of their ability to contribute to quality of life, well-being and prevention of pathologies.

It has become clear that a good diet does not mean satisfying energy, vitamin and mineral requirements alone. Secondary metabolites, such as phenolic antioxidant molecules, are not essential in the short term for consumer well-being. However, in terms of populations, in the long term, their presence in the diet appears to be a health-promoting factor.

To enrich and clarify decision-making in consumption, we should establish knowledge in as diverse a range as possible diversity of fruits and vegetables, including tropical fruits, which numerically form the majority of biodiversity in consumption (Fahrasmane, 2006; Fahrasmane, Ganou, & Aurore, 2007). The impact of production conditions and post-harvest treatments on the nutritional and physiological quality of crops should be determined, and methods developed to obtain from plants compounds with biological properties (McCreight & Ryder, 2004).

Conclusions

The products of banana production, which are consumed globally, make this crop an object of common interest. Characterisation must be undertaken of its content and concentration of useful biomolecules. The variety of harvesting methods, post-harvesting treatments and consumption methods used throughout the world make bananas and plantain a useful model for investigating quality and its development in fruits and vegetables, through the processes from field to table. Consumption forms (fresh or processed) should also be taken into account, in terms of quality of products consumed, and the dynamics of antioxidant and other bioactive compounds.

The banana family has a wide biodiversity, with many strains, selections and cultivars grown. Thus they contain genes for certain specific desirable and useful characteristics that may be considered for the creation of targeted quality varieties. The skin of the Cavendish subgroup fruits, which represents a major part of the fruit mass (30%), is far richer than the pulp in antioxidant compounds. The various parts harvested, in addition to the co-products and by-products, deserve consideration.

Downstream of production processes, quality products should be developed on the basis of innovative individual operations (Haxaire, 2001; Palou, Lopez-Malo, Barbosa-Canovas, Welti-Chanes, & Swanson, 1999; Premakumar & Khurdiya, 2002).

To promote the presence of bananas, and tropical fruits and vegetables, in the modern consumer's shopping basket, we need to develop elements of knowledge to enable the emergence of crops and products in phase with the changing motivations of today's consumers. The research approach should preferably be integrative, taking into consideration the great biodiversity of resources, functional genomics (Mbeguie-A-Mbeguie *et al.*, 2007), the agro-pedoclimatic production conditions, development and maturation physiology, and post-harvest evolution of useful compounds under different technological and/or culinary treatments (Klein & Kurilich, 2000).

Innovative treatment and molecule extraction technologies, as well as increasingly efficient analytical tools, offer a real possibility of better understanding fruit and vegetable contents, including bananas, in terms of useful microconstituents, and how they change in the course of crop development and post-harvest life.

The physiological impact of fruits and vegetables on the consumer is huge, because it concerns functions as diverse as digestive, hepatic, circulatory, renal and ocular systems. An inventory of traditional uses demonstrates that bananas have positive effects on certain physiological functions.

The research operational structures must be as close as possible to the places of production, to ensure optimum integration of the eco-physiological reality of target resources in terms of antioxidant properties. In our joint research unit, UMR QUALITROP, created in 2006, in Guadeloupe, collaborative projects are being developed on bananas to offer new resources and innovative products.

References

Adams, M. R. (1980). *The small-scale production of vinegar from bananas.* Tropical Products Institute. 56/62 Grays Inn Road London WC1X8LU. Overseas Development Administration.

Aguirre-Cruz, A., Alvarez-Castillo, A., Yee-Madeira, H., & Bello-Pérez, L. A. (2008). Production of fiber-rich powder by the acid treatment of unripe banana flour. *Journal of Applied Polymer Science, 109*(1), 382–387.

Akubor, P. I., Obio, S. O., Nwadomere, K. A., & Obiomah, E. (2003). Production and quality evaluation of banana wine. *Plant Foods for Human Nutrition, 58*, 1–6.

Anonymous (1981). *Pour mieux se nourrir en Guadeloupe.* Comité Guadeloupéen pour la journée mondiale de l'alimentation. pp. 1–47.

Aparicio-Saguilàn, A., Sàyago-Ayerdi, S. G., Vargas-Torres, A., Tovar, J., Ascencio-Otero, T. E., & Bello-Pérez, L. A. (2007). Slowly digestible cookies prepared from resistant starch-rich lintnerized banana starch. *Journal of Food Composition and Analysis, 20*, 175–181.

Apfelbaum, M., Romon, M., & Dubus, M. (2004). *Diététique et nutrition*, (6th éd.). Paris, France: Masson.

Aurora, A., & Sharma, M. P. (1990). Use of banana in non-ulcer dyspepsia. *Lancet, 335*, 612–613.

Bakry, F., Carreel, F., Caruana, M.-L., Côte, F.-X., Jenny, C., & Tézenas du Moncel, H. (1997). Les bananiers. In A. Charrier, M. Jacquot,

S. Hamon, & D. Nicolas (Eds.), *L'amélioration des plantes tropicales* (pp. 109–139). France: CIRAD ORSTOM.

Baldry, J., Coursey, D. G., & Howard, G. E. (1981). The comparative consumer acceptability of triploid and tetraploid banana fruit. *Tropical Science*, *23*, 33–66.

Bello-Pérez, L. A., Agama-Acevedo, E., Sanchez-Hernandez, L., & Paredez-Lopez, O. (1999). Isolation and partial characterization of banana starches. *Journal of Agricultural and Food Chemistry*, *47*(3), 854–857.

Belou, C. (1988). In: *Les délices du potager*. France: Vie & Santé.

van den Berg, H., Faulks, R., Fernando Granado, H., Hirshberg, J., Olmedilla, B., Sandmann, G., et al. (2000). The potential for the improvement of carotenoids levels in foods and the likely systemic effects. *Journal of the Science of Food and Agriculture*, *80*, 880–912.

Bimbenet, J. J., & Trystram, G. (2005). Le point des recherches en génie des procédés alimentaires. *Industries Alimentaires et Agricoles*, *122*(3), 8–18.

Boudhrioua, N., Giampaoli, P., & Bonazzi, C. (2003). Changes in aromatic components of banana during ripening and air-drying. *Lebensmittel-Wissenschaft und-Technology*, *36*, 633–642.

Bugaud, C., Chillet, M., Beauté, M. P., & Dubois, C. (2006). Physicochemical analysis of mountain bananas from the French West Indies. *Scientia Horticulturae*, *108*, 167–172.

Bukusuba, J., Muranga, F. I., & Nampala, P. (2008). Effect of processing technique on energy density and viscosity of cooking banana: implication for weaning foods in Uganda. *International Journal of Food Science and Technology*, *43*, 1424–1429.

Carreño, S., & Aristizàbal, L. (2003). Utilisation de bananes plantain pour produire du vin. *InfoMusa*, *12*(1), 2–4.

Champion, J. (1963). *Le bananier*. Paris, France: Maisonneuve et Larose. 263 pp.

Chung, S. L., & Meyers, S. P. (1978). Bioproteins from banana wastes. *Developments in Industrial Microbiology*, *20*, 723–731.

CIQUAL – CNEVA (1993). *Répertoire général des aliments*. In: *Table de composition des fruits exotiques de cueillette d'Afrique*, *Vol. I*. France: ORSTOM Editions/Tec & Doc Lavoisier/INRA Editions. pp. 8–12.

Cosio, R., & René, F. (1996). Composés volatils de la banane. II – Etude comparative de deux méthodes d'extraction appliquées à la pulpe de banane: cavendish, poyo. *Sciences des aliments*, *16*(5), 515–528.

Crozier, A., Yokota, T., Jaganath, I. B., Marks, S. C., Salmarsh, M., & Clifford, M. N. (2006). Secondary metabolites in fruits, vegetables, beverages and other plant-based dietary components. In A. Crozier, M. N. Clifford, & H. Ashihara (Eds.), *Plant secondary metabolites: Occurrence, structure and role in the human diet*. Oxford, UK/Iowa, USA/Victoria, Australia: Blackwell Publishing Ltd, ISBN 1405125098.

Davey, M. W., Stals, E., Ngoh-Newilah, G., Tomekpe, K., Lusty, C., Markham, R., et al. (2007). Sampling strategies and variability in fruit pulp micronutrient contents of West and Central African bananas and plantains (*Musa* species). *Journal of Agricultural and Food Chemistry*, *55*(7), 2633–2644.

Davies, G. (1993). Production domestique de la bière de banane dans la région de Mpigi, Ouganda. *InfoMusa*, *2*(1), 12–15.

Englberger, L. (2003). Des bananes riches en caroténoïdes en Micronésie. *InfoMusa*, *12*(2), 2–5.

Enwefa, C. (1991). Biomass production from banana skins. *Applied Microbiology and Biotechnology*, *36*, 283–284.

Espiard, E. (2002). *Introduction à la transformation industrielle des fruits. Banane*. Londres/Paris/New York: Editions Tec & Doc. pp. 103–111.

Evelin, M. A., Jacob, J. P., & Vijayanand, D. (2007). Packaging and storage studies on spray dried ripe banana powder under ambient conditions. *Journal of Food Science and Technology*, *44*(1), 16–21.

Fahrasmane, L. (2006). Pour un développement des recherches sur les potentialités de la biodiversité végétale à protéger la santé du consommateur. *Fruits*, *61*(3), 211–222.

Fahrasmane, L., Ganou, B., & Aurore, G. (2007). Harnessing the health benefits of plant biodiversity originating from the American tropics in the diet. *Fruits*, *62*(4), 213–222.

FAOSTAT (2004). Available from http://faostat.fao.org

Fasolin, L. H., de Almeida, G. C., Castanho, P. S., & Netto-Oliveira, E. R. (2007). Cookies produced with banana meal: chemical, physical and sensorial evaluation. *Cienca e Tecnologica de Alimentos*, *27*(3), 524–529.

Fernandes, F. A. N., & Rodriges, S. (2007). Ultrasound as pre-treatment for drying of fruits: dehydration of banana. *Journal of Food Engineering*, *52*(2), 261–267.

Goswami, B., & Borthakur, A. (1996). Chemical and biochemical aspects of developing culinary banana (*Musa* ABB) 'Kachkal'. *Food Chemistry*, *55*(2), 169–172.

Guerrero, S., Alzamora, S. M., & Gerschenson, N. (1994). Development of shelf-stable banana purée by combined factors: microbial stability. *Journal of Food Protection*, *57*(10), 902–907.

Hammond, J. B., Egg, R., Diggins, D., & Coble, G. C. (1996). Alcohol from bananas. *Bioresources Technology*, *56*(1), 125–130.

Happi Emaga, T., Herinavalona Andrianaivo, R., Wathelet, B., Tchango Tchango, J., & Paquot, M. (2007). Effects of the stage of maturation and varieties on the chemical composition of banana and plantain peels. *Food Chemistry*, *103*(2), 590–600.

Haxaire, L. (2001). Préparation des fruits et légumes: pallier la fragilité en améliorant les procédés. *Process*, *1173*, 37–38.

Heo, H. J., Choi, S. J., Choi, S.-G., Shin, D.-H., Lee, J. M., & Lee, C. Y. (2008). Effects of banana, orange and apple on oxydative stress-induced neurotoxicity in PC 12 cells. *Journal of Food Science*, *73*(2), 28–32.

Hernandez-Uribe, J. P., Rodrigez-Ambriz, L. A., & Bello-Pérez, L. A. (2008). Obtention of fructose syrup from plantain (*Musa paradisiaca* L.) starch. Partial characterization. *Intercienca*, *33*(5), 372–376.

Hertog, M. G. L., Feskens, E. J. M., Hollman, P. C. H., Katan, M. B., & Kromhout, D. (1993). Absorption and disposition kinetics of the dietary antioxidant quercetin in man. *Lancet*, *342*, 1007–1011.

Idachaba, M., & Onyezili, F. (1994). Physical, chemical and microbiological considerations in processing plantain (*Musa paradisiaca* L.) into ''Medi'', a Nigerian food drink. *Sciences des Aliments*, *14*(2), 229–234.

Joffe, M., & Robertson, A. (2001). The potential contribution of increased vegetable and fruit consumption to health gain in the European Union. *Public Health Nutrition*, *4*, 893–901.

Jordan, M. J., Tandon, D., Shaw, P. E., & Goodner, K. L. (2001). Aromatic profile of aqueous banana essence and banana fruit by gas chromatography-mass spectrometry (GC–MS) and gas chromatography-olfactometry (GC-O). *Journal of Agricultural and Food Chemistry*, *49*, 4813–4817.

Juarez-Garcia, E., Agama-Acevedo, E., Sayago-Ayerdi, S. G., Rodriguez-Ambriz, S. L., & Bello-Pérez, L. A. (2006). Composition, digestibility and application in breadmaking of banana flour. *Plant Foods for Human Nutrition*, *61*, 131–137.

Kajuna, S. T. A., Bilanski, W. K., & Mittal, G. S. (1997). Textural changes of bananas and plantain pulp during ripening. *Journal of the Science of Food and Agriculture*, *75*, 244–250.

Kanazawa, K., & Sakakibara, H. (2000). High content of dopamine, a strong antioxydant, in *Cavendish* banana. *Journal of Agricultural and Food Chemistry*, *48*(3), 844–848.

Klein, B. P., & Kurilich, A. C. (2000). Processing effects on dietary antioxidants from plant foods. *Hortscience*, *35*, 580–584.

Kondo, S., Kittikorn, M., & Kanlayanarat, S. (2005). Preharvest antioxidant activities of tropical fruit and the effect of low temperature storage on antioxidants and jasmonates. *Postharvest Biology and Technology*, *36*, 309–318.

Lassoudière, A. (2007). *Le bananier et sa culture*. France: Editions QUAE.

Laville, E. (1994). *La Protection des fruits tropicaux après récolte*. Paris, France: Tec & Doc Lavoisier.

Lehmann, U., Jacobasch, G., & Schmiedl, D. (2002). Characterization of resistant starch type III from banana (*Musa acuminata*). *Journal of Agricultural and Food Chemistry*, *50*, 5236–5240.

Leklem, J. E. (1999). Vitamin B6. In M. Shils, J. A. Olson, M. Shike, & A. C. Ross (Eds.), *Nutrition in health and disease* (9th ed.). (pp. 413–422) Baltimore: Williams et Wilkins.

Lemaire, H., Reynes, M., Tchango Tchango, J., Ngalani, J. A., & Guillaumont, A. (1997). Aptitude à la friture de cultivars de plantains et bananes à cuire. *Fruits*, *52*(4), 273–282.

Lescot, T. (1990). The importance of plantains and cooking bananas in Africa: outlets for the subtropical zones. *Infomusa*, *9*(1), 25–28.

Lescot, T. (1997). Culture du bananier plantain et durabilité des systèmes de production. *Fruits*, *52*(4), 233–245.

McCreight, J. D., & Ryder, E. J. (2004). In: *XXVI international horticultural congress: Advances in vegetable breeding*. Toronto: International Society for Horticultural Science.

Macku, C., & Jennings, W. G. (1987). Production of volatiles by ripening bananas. *Journal of Agricultural and Food Chemistry*, *35*, 845–848.

MacNaughton, W. K., & Wallace, J. L. (1989). A role for dopamine as an endogenous protective factor in the rat stomach. *Gastroenterology*, *96*, 972–980.

Maltini, E., & Giangiacomo, R. (1976). Aspetti tecnici della liofilizzazione delle fragole e delle banane. *Industrie Alimentari*, *33*, 49–55.

Marchal, J. (1993). The quality of dessert bananas and plantains. *Fruit*, *8*(1), 40–44.

Marriott, J. (1980). Bananas – physiology and biochemistry of storage and ripening for optimum quality. *CRC Critical Reviews in Food Science and Nutrition*, *13*, 41–88.

Marriott, J., & Lancaster, P. A. (1983). Bananas and plantains. In H. T. Chan Jr. (Ed.), *Handbook of tropical foods* (pp. 85–143). New York/Basel: Marcel Dekker, Inc.

Mattei, A. (1973). Analyse de l'émission volatile de la banane (Cultivar "Poyo" groupe Cavendih). *Fruits*, *28*, 231–239.

Mbeguie-A-Mbeguie, D., Hubert, O., Sabau, X., Chillet, M., Fils-Lycaon, B., & Baurens, F.-C. (2007). Use of suppression subtractive hybridization approach to identify genes that are differentially expressed during early banana fruit development undergoing changes in ethylene responsiveness. *Plant Science*, *172*, 1025–1036.

Millan-Testa, C. E., Mendez-Montealvo, M. G., Ottenhof, M.-A., Farhat, I. A., & Bello-Pérez, L. A. (2005). Determination of the molecular and structural characteristics of okenia, mango, and banana starches. *Journal of Agriculture and Food Chemistry*, *53*(3), 495–501.

da Mota, R. V., Lajolo, F. M., Ciacco, C., & Cordenunsi, B. R. (2000). Composition and functional properties of banana flour from different varieties. *Stärke*. [*Starch*], *52*(2–3), 63–68.

Murray, D. L., & Raynolds, L. T. (2000). Alternative trade in bananas: obstacles and opportunities for progressive social change in the global economy. *Agricultural and Human Values*, *17*, 65–74.

Nakasone, H. Y., & Paull, R. E. (1999). *Tropical fruits. Banana*. Wallingford, UK/New York, USA: CABI Publishing. pp. 103–131.

Ngalani, J. A., Signoret, A., & Crouzet, J. (1993). Partial purification and properties of plantain polyphenoloxydase. *Food Chemistry*, *48*, 341–347.

Nimsung, P., Thongngam, M., & Naivikul, O. Composition, morphological and thermal properties of green banana flour and starch. 45th Kasetsart University Annual Conference, 30th January–2nd February 2007, Kasetsart University, Kasetsart, Thailand.

Nogueira, J. M. F., Fernandes, P. J. P., & Nascimento, A. M. D. (2003). Composition of volatiles of banana cultivars from Madeira Island. *Phytochemical Analysis*, *14*, 87–90.

Nuñez-Santiago, M. C., Bello-Pérez, L. A., & Tecante, A. (2004). Swelling-solubility characteristics, granule size distribution and rheological behavior of banana (*Musa paradisiaca*) starch. *Carbohydrate Polymers*, *56*, 65–75.

Oliveira do Nascimento, J. R., Junior, A. V., Bassinello, P. Z., Mainardi, J. A., Purgato, E., & Lajolo, F. M. (2006). Beta-amylase expression and starch degradation during banana ripening. *Postharvest Biology and Technology*, *40*(1), 41–47.

Osorio-Diaz, P., Aguilar-Sandoval, A., Agama-Acevedo, E., Rendon-Villalobos, R., Tovar, J., & Bello-Pérez, L. A. (2008). Composite durum wheat flour/plantain starch white salted noodles: proximal composition, starch digestibility, and indigestible fraction content. *Cereal Chemistry*, *85*(3), 339–343.

Palou, E., Lopez-Malo, A., Barbosa-Canovas, G. V., Welti-Chanes, J., & Swanson, B. G. (1999). Polyphenoloxidase activity and color of blanched and high hydrostatic pressure treated banana purée. *Journal of Food Science*, *64*(1), 42–45.

Pérez, A. G., Cert, A., Rios, J. J., & Olias, J. M. (1997). Free and glycosidically bound volatile compounds from two bananas cultivars: Valery and Pequeña Enna. *Journal of Agricultural and Food Chemistry*, *45*, 4393–4397.

Phoungchandang, S., & Woods, J. L. (2000). Solar drying of bananas: mathematical model, laboratory simulation, and field data compared. *Food Science and Technology*, *65*(6), 990–996.

Piraux, M. (2006). In: *Consommer éthique: Un choix*. Bruxelles: Luc Pire.

Premakumar, K., & Khurdiya, D. S. (2002). Effect of microwave blanching on the nutritional qualities of banana puree. *Journal of Food Science and Technology*, *39*(3), 258–260.

Rabbani, G. H., Teka, F. T., Saha, S. K., Zaman, B., Majid, N., Khatun, M., et al. (2004). Green banana and pectin improve small intestinal permeability and reduce fluid loss in Bangladeshi children with persistent diarrhea. *Digestive Diseases and Sciences*, *49*(3), 475–484.

Rieger, M. (2006). Banana and plantain. In: *Introduction to fruit crops* (pp. 75–88). New York/London/Oxford: Haworth Food & Agricultural Product Press/The Haworth Press, Inc.

Roubert, E. (2005). Des marchés d'avenir. *Référence Innovation*, *1*, 74–75.

Salvador, A., Sanz, T., & Fiszman, S. M. (2006). Changes in colour and texture and their relationship with eating quality during storage of two different dessert bananas. *Postharvest biology and technology*, *43*(3), 319–325.

Salvatore, S., Pellegrini, N., Brenna, O. V., Del Rio, D., Frasca, G., Brighenti, F., et al. (2005). Antioxidant characterization of some Sicilian edible wild greens. *Journal of Agricultural and Food Chemistry*, *53*, 9465–9471.

Schiota, H. (1993). New esteric components in the volatiles of banana fruit (*Musa sapientum* L.). *Journal of Agriculture and Food Chemistry*, *41*, 2056–2062.

Shreck, A. (2005). Resistance, redistribution, and power in the fair trade banana intitiative. *Agricultural and Human Values*, *22*, 17–29.

Siriwong, W., Tulyathan, V., & Waiprib, Y. (2003). Isolation and physicochemical characterization of starches from different banana varieties. *Journal of Biochemistry*, *27*(6), 471–484.

Sojo, M. M., Nunez-Delicado, E., Sanchez-Ferrer, A., & Garcia-Carmona, F. (2000). Oxidation of salsolinol by banana pulp polyphenol oxidase and its kinetic synergism with dopamine. *Journal of Agricultural and Food Chemistry*, *48*, 5543–5547.

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). *Bananas*, (3rd ed.). London: Longman.

Tramil (1999). *Pharmacopée végétale caribéenne*. Martinique, France: Editions Emile Désormeaux, Fort-de-France.

de la Torre-Gutiérrez, L., Chel-Guerrero, L. A., & Betancur-Ancona, D. (2008). Functional properties of square banana *(Musa balbisiana)* starch. *Food Chemistry*, *106*, 1138−1144.

Turner, D. W. (1994). Bananas and plantains. In B. Shaffer, & P. C. Anderson (Eds.), *Subtropical and tropical crops. Handbook of environmental physiology of fruit crops, Vol. 2* (pp. 37−64). Boca Raton, FL: CRC Press.

Valmayor, R. V. (2000). Cooking bananas − classification, production and utilization in South-East Asia. *Infomusa*, *9*(1), 28−30.

Verde Mendez, C. M., Forster, M. P., Rodriguez-Delgado, M. A., Rodriguez-Rodriguez, E. M., & Diaz Romero, C. (2003). Content of free phenolic compounds in bananas from Tenerife (Canary Islands) and Ecuador. *European Food Research and Technology*, *217*(4), 287−290.

Waliszewski, K. N., Aparicio, M. A., Bello, L. A., & Monroy, J. A. (2003). Changes of banana starch by chemical and physical modification. *Carbohydrate Polymers*, *52*, 237−242.

Woolfe, J. A. (1992). *Sweet potato an untapped food resource*. Cambridge/Port Chester/Melbourne/Sydney: Cambridge University Press.

World Cancer Research Fund/American Intitute for Cancer Research (2007). *Food, nutrition, physical activity, and the prevention of cancer: A global perspective*. Washington, DC: AICR.

Yang, C. P., Nong, Z. R., Lu, J. L., Lu, L., Xu, J. S., Han, Y. Z., et al. (2004). Banana polyphenol oxidase: occurrence and change of polyphenol oxidase activity in some banana cultivars during fruit development. *Food Science and Technology Research*, *10*(1), 75−78.

Zhang, P., Whistler, R. L., BeMiller, J. N., & Hamaker, B. R. (2005). Banana starch: production, physicochemical properties, and digestibility − a review. *Carbohydrates Polymers*, *59*(4), 443−458.