Food Sci. Biotechnol. Vol. 16, No. 6, pp. 889 ~ 893 (2007)

Food Science and Biotechnology

Optimization of the Processing Parameters for Green Banana Chips and Packaging within Polyethylene Bags

Pranabendu Mitra, Eun-Mi Kim, and Kyu Seob Chang*

Department of Food Science and Technology, Chungnam National University, Daejeon 305-764, Korea

Abstract The demand of quality green banana chips is increasing in the world snacks market, therefore, the preparation of quality chips and their subsequent shelf life in packaging were evaluated in this study. Banana slices were fried in hot oil to the desired moisture content (2-3%) and oil content (40%) in chips at 3 different temperatures, and the impact of different pre-treatments were compared by sensory assessment. A linear relationship between time and temperature was used to achieve the optimal processing conditions. Banana slices fried at the lower temperature of 145°C took longer to reach the desired chip qualities, but gave the best results in terms of color and texture. Blanching was the most effective pre-treatment for retaining the light yellow color in finished chips. For extending the shelf life of chips, moisture proof packaging in double layer high density polyethylene was more effective than single layer low density polyethylene.

Keywords: green banana chip, optimization, processing parameter, packaging

Introduction

Bananas are one of the major fruits in tropical areas with respect to popularity, availability, production, and consumption. It is one of the most delicious fruits in the world (1). The importance of this fruit is due to its high calorific and nutritive value and its versatile use by consumers. Bananas contain an appreciable amount of vitamin B and significant amounts of vitamins A and C, in addition to minerals such as potassium, phosphorus, calcium, and iron (2, 3).

Bananas can be processed into chips, ice cream, jam, and confectionery products. Green banana chips are a crispy snack food similar to potato chips. Mature but unripe bananas are used to produce green banana chips. Chips prepared by deep fat frying are also popular (4). Deep-fat/oil frying is one of the oldest cooking methods for producing the desired texture and flavor attributes of snack food products. Deep-fat frying can be defined as the process of drying and cooking through contact with hot oil (5). High heat transfer rates are largely responsible for the development of the desired sensorial properties in fried products (6). However, it appears that longer times and lower frying temperatures lead to higher final oil contents in fried potato products (7). Potato chips have an oil content ranging from 35-45% (wet basis) that gives the product the unique texture-flavor combination that makes them so desirable (4, 8).

The total banana production in Bangladesh in the year of 2003-04 was 706,600 tons (9). Bananas are not seasonal in nature like many other fruit crops and are available in large quantities throughout the year. A very large number of bananas are in cultivation in Bangladesh every year. These are known by different local names, namely Sagar, Champa, and Sarbi, etc. Bananas are a highly perishable fruit and their preservation in the tropical climate of Bangladesh is a great problem. Bananas cannot be preserved for long periods after harvesting and there are insufficient existing storage systems for them in Bangladesh. Farmers will be encouraged to increase production if spoilage can be prevented by proper preservation, which will also result in greater consumption.

Packaging is the most important consideration in preserving banana chips. The quality of the chips depends on two factors: the extent of lipid oxidation and the amount of absorbed moisture while the latter is inversely related to the crispness of the chips (10).

The aims of this study were to develop a standardized methodology for the manufacture of quality banana chips and their subsequent storage. The specific objectives were: 1) to analyze the banana composition, and to study the processing aspects of chip production, 2) to study the quality aspects of chip production, 3) to observe the effects of different treatments and, 4) to study the preservation of chips.

Materials and Methods

Materials Good quality seedless green bananas (*Musa acuminata*) and good quality soybean oil (Pran Co., Ltd., Bangladesh) were obtained from a local market, and green bananas were kept at 14±1°C and a relative humidity of 90-95% after packing in polyethylene bags to increase the green shelf-life of the bananas. Potassium meta-bisulphite (KMS, Sigma, St. Louis, MO, USA), sodium chloride (NaCl, Junsei Chemical Co., Ltd., Tokyo, Japan), sodium-bicarbonate ($NaHCO_3$, Duksan Chemicals Co., Ltd., Korea) and single layer low density polyethylene (LDPE) and double layer high density polyethylene (HDPE) packaging materials were also used.

Analysis of the general components of green banana pulp The moisture content of green banana pulp was determined by heating 5 g of green banana pulp at 105°C

*Corresponding author: Tel: +82-42-821-6727; Fax: +82-42-821-8897
E-mail: changks@cnu.ac.kr
Received January 3, 2007; accepted May 9, 2007

for 24 hr in an oven (11). The total solid (TS) percentage was determined according to the AOAC (11). Ash content was measured in duplicate by heating the residues from moisture determination at 550°C for 24 hr as described by the AOAC (11). Protein content was determined using the Kjeldahl method (11). Oil content was determined by the method of Soxhlet and ascorbic acid was determined using the 2,6-dichloroindophenol titration method as described by Ranganna (12). Total soluble solid (TSS) was measured by a digital refractometer palette100 (Atago, Kyoto, Japan), and pH was measured by a pH meter (model 230A; Orion, Berverly, MA, USA). Acidity was determined by the titration method of the AOAC (11).

Sugar analyses were done as described by Forster *et al.* (13) with some modifications. All sugars were extracted from 3 g of homogenized banana in 20 mL of ethanol solution (95%). The solution was then passed through 0.45 μL Whatman filter paper and then through a Sep-Pak® plus C18 Cartridge (WAT036575), which was activated with 5 mL of methanol and 5 mL of ultra pure water. One mL of the filtration solution was passed through the Sep-Pak® Cartridge. The cartridge was then washed with 5 mL of water. Glucose, fructose, and sucrose were determined by HPLC with a Refractive Index detector (Futecs Co. Ltd., Korea) injecting 20 μL of standard solutions or sample extracts and eluting with a mobile phase of de-ionized water through a Carbo Sep Cho-620 column (300× 6.5 mm) at a flow rate of 0.5 mL/min at 90°C. The HPLC peaks were identified by comparing the retention times with those of commercial standards of sucrose, glucose, and fructose.

Preparation of banana chips The steps used for the processing of green banana chips are shown in Fig. 1. Bananas were sliced to a thickness of 3 mm by a mechanical slicer (SL-250; Kenwood Ltd., Hampshire, UK) and the slices were peeled manually. The peeled slices were then washed with jets of water at room temperature to remove dirt and prevent the Maillard reaction which causes browning on the surface of banana slices. After pre-treatment of banana slices, 15 slices were deep-fried in hot oil at each of the 3 temperatures (145, 165, and 185°C). Slices were fried at different times depending on the oil temperature until the final moisture content was 3%. For each batch, the slices were drained after frying over a wire screen for 5 min and allowed to cool to room temperature before analysis. Finally, the chips were packed in 2 different packages, one using single layer LDPE and the other using double layer HDPE and kept at ambient conditions for storage.

Pre-treatment of banana slices To improve the sensory attributes of banana slices, several pre-treatments were tested and the best pre-treatment was selected by sensory evaluation. The pre-treatments tested were: blanching (banana slices were blanched in hot water at 85°C for 1 min), soaking in 0.03% KMS solution, 0.1% $NaHCO_3$ solution, 1% NaCl solution, or a combination of all 3 for 5 min.

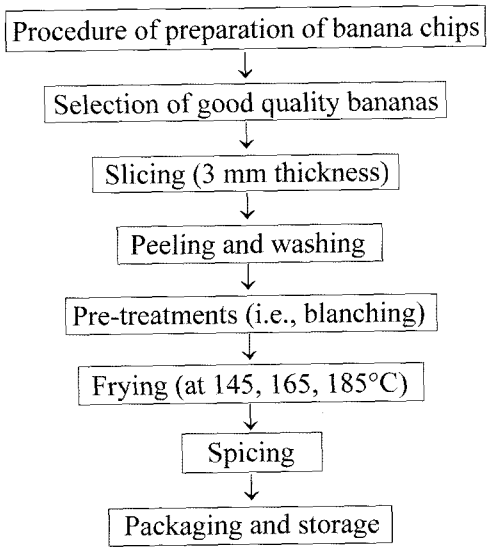

Fig. 1. Flow chart for the processing of green banana chips.

Frying of banana slices The frying temperature was controlled by an electrical heater connected to a thermostat. A banana slice to oil ratio (w/w) of 1:25 was chosen which gave an initial temperature drop of 10°C with 145, 165, and 185°C frying temperature. Banana slices were placed in hot oil when the temperature was 5°C higher than the set temperature.

Determination of moisture and oil contents of banana chips The moisture content of chips was determined by the AOAC method of oven drying (11) and the oil content of chips was determined by the soxhlet extraction method described by Ranganna (12).

Sensory evaluation of various pre-treated chips Sensory evaluation was done according to the 9-point hedonic scale. Processed chips were tested by a panel of 10 judges, 5 women and 5 men. Their ages ranged from 22 to 35 years. All judges were conversant with the factors governing the quality of the product. The banana chips prepared for each test sample were coded with a random 2 digit number. The panelists were asked to evaluate the color, flavor, texture, and overall acceptability of the chips by giving a score ranging from 1 (dislike extremely) to 9 (like extremely).

Packaging and storage Chips were packed in 2 different packaging systems, one using single layer LDPE and the other using double layer HDPE, and the samples were stored at ambient conditions. Samples were drawn at 5-day intervals and the moisture content was determined and compared with the initial moisture content of the chips.

Statistical analysis The experimental data were analyzed (ANOVA) with the computer program MSTAT version 6.0 to determine any significant differences among

the pre-treatments.

Results and Discussion

General components of green banana pulp The average moisture content, total solid (TS), total soluble solid (TSS), sugar (sucrose, glucose, and fructose), ash, protein, fat, pH, acidity, and ascorbic acid content in green banana pulp are shown in Table 1. These nutrient data are within the ranges reported in banana composition charts (2, 12, 13). As shown in Table 1, the sucrose content was slightly lower and the glucose content was slightly higher than the values reported in the banana composition chart (13), and the fructose content was similar to that reported by Forster *et al.* (13).

Determination of moisture content in banana chips The oven drying method (11) was used to determine the moisture content of chips fried at 145, 165, or 185°C for different lengths of time. The impact of frying time and frying oil temperature on moisture loss during deep-fat frying was studied to select the most suitable frying condition for green banana chips. Analysis of variance (ANOVA) of the data indicate that the effects of frying time and temperature on moisture loss were significant at $p<0.01$. The moisture contents of chips fried at different times and temperatures are shown in Fig. 2. The minimum frying time required to reach the desired final moisture content of 3% was 6.5 min at 145°C, 4.5 min at 165°C, and 3.5 min at 185°C. Reddy and Das (14) suggested that to lengthen the shelf life of potato chips, the moisture content of the chips should be 1-3%. A relationship was observed (R^2 values were 0.997, 0.991, and 0.995 for 145, 165, and 185°C, respectively) between frying time and moisture loss such that the moisture content decreased with frying time. This shows that there is a fairly linear relationship between frying time and moisture loss at achieving 3% moisture content in banana chips.

Oil uptake of green banana chips The effects of frying time and temperature on oil imbibed in banana chips fried for different times at 145, 165, and 185°C are shown in Fig. 3. The range of oil uptake by banana chips was 39.2-40.2% for the 3 different times and temperatures (6.5 min at 145°C, 4.5 min at 165°C, 3.5 min at 185°C). A significant correlation (R^2 values were 0.998, 0.991, and 0.995 for 145, 165, and 185°C, respectively) was found between oil uptake and frying time. The linear relationship between time and oil uptake displayed a slope close to unity. Gamble *et al.* (15) reported that the relationship between time and oil uptake was linear for fried potato chips (R^2 = 0.998). The results in Fig. 3 show that the oil content in banana slices increased with frying time at all frying

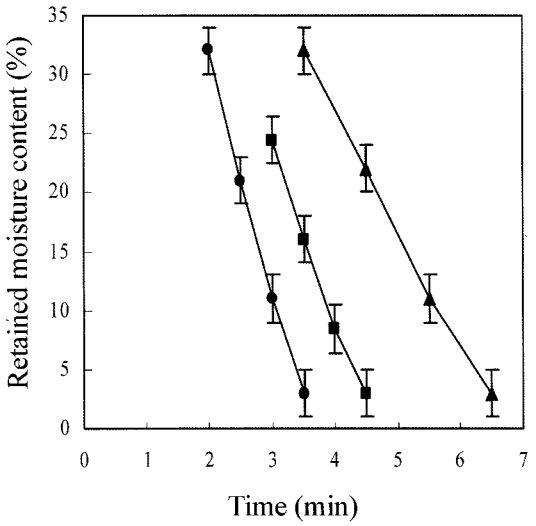

Fig. 2. Effects of time and frying temperature on the moisture content of banana chips. ▲ 145°C, ■ 165°C, ● 185°C.

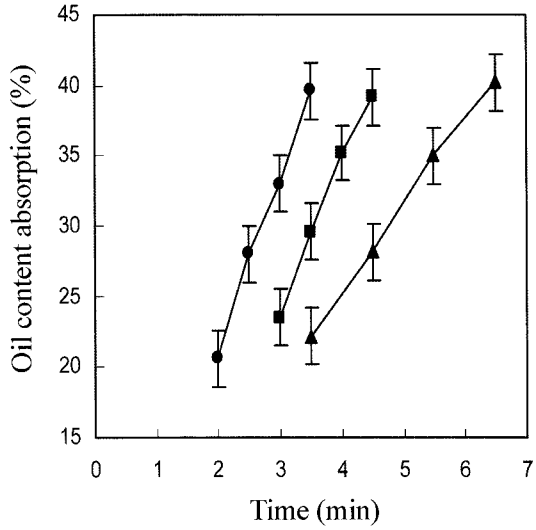

Fig. 3. Effects of time and frying temperature on oil uptake by banana chips. ▲ 145°C, ■ 165°C, ● 185°C.

temperatures. The rate of oil uptake was highest at the highest frying temperature of 185°C and lowest at the lowest frying temperature of 145°C for a given amount of frying time. This indicates that the rate of oil uptake depends on temperature. The oil content of potato chips for all frying times was independent of oil temperature and the thickness of the slices (14). The frying of banana slices

Table 1. General components of green banana pulp[1)]

	Moisture (%)	T.S. (%)	T.S.S. (%)	Sucrose (%)	Glucose (%)	Fructose (%)	Ash (%)	Protein (%)	Fat (%)	pH	Acidity (%)	Ascorbic acid (mg/100 g)
Banana pulp	73.90	26.10	16.20	10.90	1.70	1.54	0.91	1.18	0.02	5.29	0.27	14.90

[1)]T.S., Total solid; T.S.S., Total soluble solid.

can be considered as a two way diffusion process in which water is removed due to evaporation by heat transferred from hot oil, and oil diffuses into the slices filling the space vacated by water (16).

Effect of frying temperature on the color of banana chips Banana slices were fried at 145, 165, and 185°C for different periods of time to obtain a final moisture content of a 3%. The color at the end of the minimal frying time was determined with a colorimeter (CR-300; Minolta, Osaka, Japan).The results are shown in Table 2 and reveal that the color of chips fried at 165 and 185°C were unacceptable due to dark color and spots on the chips. Misra and Premchand (17) reported that the light yellow color of potato chips was preferable. Chips fried at 145°C for 6.5 min exhibited a light yellow color.

For a detailed evaluation of the color of chips fried at 145, 165, and 185°C, the chips were evaluated by a test panel consisting of 10 judges. The mean scores for color preference are presented in Table 3. The results show that there was a significant ($p<0.01$) difference in color acceptability among the chips prepared at different times and temperatures. The chips fried at 145°C for 6.5 min were the most preferred having a mean rating score of 8.1 out of 9. The second highest score of 6.6 was obtained for chips fried at 165°C for 4.5 min while the lowest score of 5.6 was assigned to chips fried at 185°C for 3.5 min. Therefore, the frying of chips at 145°C for 6.5 min was selected as the best method to achieve the desired light yellow color of chips having a 3% moisture content. The development of color in chips is considered to be a non-enzymatic browning reaction between the sugar and protein fractions of banana slices as reported by Reddy and Das (14).

Table 3. Mean scores for color preference at frying temperatures of 145, 165, and 185°C

Frying temperature (°C)	Mean score for color
145	$8.10^{a1)}$
165	6.60^{b}
185	5.60^{c}
LSD ($p<0.01$)	0.912

[1)]Means with same superscript within a column are significantly different at $p<0.01$.

Table 4. Mean scores for color, texture, flavor and overall acceptability of different pretreated chip samples fried at 145°C

Chip type[1)]	Sensory attributes[2)]			
	Color	Flavor	Texture	Overall acceptability
Sample-1	7.70^{a}	6.9^{b}	7.40^{a}	6.90^{b}
Sample-2	7.60^{a}	6.60^{b}	7.60^{a}	6.60^{b}
Sample-3	6.40^{b}	6.30^{b}	7.30^{a}	6.50^{b}
Sample-4	6.60^{b}	7.70^{a}	7.40^{a}	6.90^{b}
Sample-5	6.70^{b}	6.70^{b}	7.00^{a}	7.70^{a}
LSD ($p<0.01$)	0.804	0.921	0.897	0.717

[1)]Sample-1, pretreatment by blanching in hot water at 85°C for 1 min; Sample-2, pretreatment in 0.03% KMS solution for 5 min; Sample-3, pretreatment in 0.1% $NaHCO_3$ solution for 5 min; Sample-4, pretreatment in 1% salt solution for 5 min; Sample-5, pretreatment by combination of 0.03% KMS, 0.1% $NaHCO_3$, and 1% salt solution for 5 min.
[2)]Means with same superscript within a column are significantly different at $p<0.01$.

Effect of pre-treatments on the quality of chips The color, flavor, texture, and overall acceptability of 5 pretreated banana chip samples fried at 145°C for 6.5 min were evaluated by a panel of 10 judges. The mean scores for color, flavor, texture, and overall acceptability of different samples are presented in Table 4.

The highest mean score for color on a scale of 1 to 9 was 7.7 which was obtained for sample-1 (blanching in hot water at 85°C for 1 min). This was followed by sample-2 (0.03% KMS) with a mean scores of 7.6 out of 9. Blanching is known to reduce enzymatic browning by destroying enzymes and this also reduces the sugar content by leaching and thus reduces the extent of color damage by the non-enzymatic browning reaction (18, 19). The scores for sample-1 indicate that blanching has an important role in color fixation. Similarly, sample-2 shows that sulphites have a positive effect on the color fixation of chips.

Pre-treatment also had significant effects on flavor acceptability. Sample-4 (1% salt) was the most preferred having the highest scores of 7.7 out of 9. On the other hand, sample-3 (0.1% $NaHCO_3$) was the least acceptable to the panelists.

In terms of texture, the panelists were not able to find any significant difference among the pre-treatments tested.

As far as the overall acceptability (color, flavor, texture) was concerned, sample-5 (0.03% KMS, 0.1% $NaHCO_3$, and 1% salt) was the most acceptable banana chip securing scores of 7.7 out of 9 compared to other samples. There were no significant differences among samples of 1, 2, 3, and 4 with regard to overall acceptability.

Packaging and storage studies of chips Banana chips with a 3% moisture content were packed in 2 different packaging systems, single layer LDPE and double layer HDPE, and stored in the laboratory at room temperature

Table 2. Effects of frying temperature on the color of banana chips

Oil temperature (°C)	Time required (min) for achieving 3% moisture content	Color
145	6.5	Light yellow
165	4.5	Yellow and light spots present
185	3.5	Dark and spots present

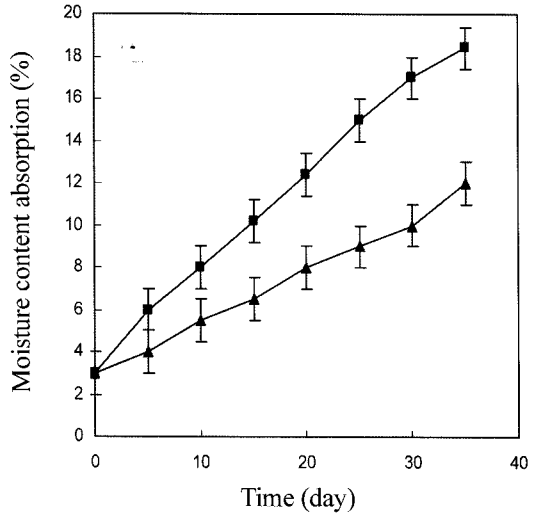

Fig. 4. Comparison of chip moisture content due to absorption for 2 different packaging systems. ■ Single layer low density polyethylene; ▲ Double layer high density polyethylene.

and humidity. The moisture content of banana chips due to absorption was determined at 5-day intervals. The results are shown in Fig. 4. After 5 days, chips in single layer LDPE had 6% moisture and chips in double layer HDPE had 4% moisture. By the 35th day, chips in single layer LDPE had 18.4% moisture and chips in double layer HDPE had 12% moisture. This shows that the rate of moisture content absorption by chips packed in double layer HDPE was lower than the chips packed in single layer LDPE during storage at ambient conditions. After 35 days, it was also found that chips in single layer LDPE had completely lost their crispiness and had an off-flavor due to rancidity. On the other hand, chips in double layer HDPE were able to hold their crispiness, flavor, and color. After 35 days, only chips in double layer HDPE were tested for their crispiness, flavor, and color without calculating moisture absorption further. After 50 days of storage, chips in double layer HDPE lost their crispiness and color, and had an off-flavor due to rancidity. The above study clearly indicated that chips packed in double layer HDPE can be stored for longer periods compared to chips in single layer LDPE. Therefore, the packaging of chips in double layer HDPE is recommended to retain the quality of chips for long term storage.

Acknowledgments

This study was supported by Korea Research Foundation (KRF).

References

1. Haque MA. Kolar Bagan. Banana Research project. BAU, Mymensingh, Bangladesh. p.1 (1988)
2. Ketiku AO. Chemical evolution of the nutritive value of varieties of banana fruits (*Musa Sepientum)* grown in Nigeria. J. Assoc. Adv. Agril. Sci. 40: 53-56 (1978)
3. Villalong MA. Physio-chemical characteristics of some banana varieties. Rev. Fac. Agron. 55: 95-107 (1983)
4. Pedreschi F, Moyano P. Effect of pre-drying on texture and oil uptake of potato chips. Lebensm. -Wiss. Technol. 38: 599-604 (2005)
5. Shahin S, Sastry SK, Bayindrili L. Heat transfer during frying of potato slices. Lebensm.-Wiss. Technol. 32: 19-24 (1999)
6. Hubbard LJ, Farkas BE. A method for determining the convective heat transfer coefficient during immersion frying. J. Food Process Eng. 22: 201-214 (1999)
7. Saguy IS, Ufheil G, Livings S. Oil uptake in deep-fat frying: A review. Oleagineux Corp Lipid 5: 30-35 (1998)
8. Garayo J, Moreira R. Vacuum frying of potato chips. J. Food Eng. 55: 181-191 (2002)
9. BBS. Bangladesh Bureau of Statistics, Statistic Division, Ministry of Planning. The Govt. of People's Republic of Bangladesh, Dhaka, Bangladesh (2005)
10. Quast DG, Karel M, Rand WM. Development of mathematical model for oxidation of potato chips as a function of oxygen pressure, extent of oxidation, and equilibrium relative humidity. J. Food Sci. 37: 673-678 (1972)
11. AOAC. Official Methods of Analysis of AOAC Intl. 16th ed. Method 920.149, 934.01, 942.05, 955.04c. Association of Official Analytical Communities, Arlington, VA, USA (1995)
12. Ranganna S. Manual of Analysis of Fruit and Vegetable Products. 2nd ed. Tata McGrew Hill Publishing Co., Ltd., New Delhi, India. pp. 506-578 (1992)
13. Forster M, Rodriguez E, Martin JD, Romero CD. Distribution of nutrients in edible banana pulp. Food Technol. Biotechnol. 41: 167-171 (2003)
14. Reddy GV, Das H. Kinetics of deep fat frying potato and optimization of process variables. J. Food Sci. Technol. 30: 105-108 (1993)
15. Gamble MH, Rice P, Selman JD. Relationship between oil uptake and moisture loss during frying of potato slices from c.v. Record UK tubers. Int. J. Food Sci. Technol. 22: 233-241 (1987)
16. Islam MN. Influence of process parameters on the effectiveness of osmotic dehydration of some fruits and vegetables. Bangladesh J. Agr. Eng. 4: 65-73 (1990)
17. Misra JB, Premchand EV. Improvement of chip color by removal of color reactants from potato tube slices by water washing. J. Food Sci. Technol. 12: 99-100 (1988)
18. Moyano PC, Pedreschi F. Kinetics of oil uptake during frying of potato slices: Effect of pre-treatments. Lebensm.-Wiss. Technol. 39: 285-291 (2006)
19. Leeratanarak N, Devahastin S, Chiewchan N. Drying kinetics and quality of potato chips undergoing different drying techniques. J. Food Eng. 77: 635-643 (2006)