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Coating of seasonings in deep-fried banana chips by electrostatic and non-electrostatic coating processes

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Abstract

Deep-fried banana chips were coated with seasonings, salt, sugar, and mixed paprika flavor. The coating methods employed electrostatic coating (varying the voltages from 30 to 50 kV), in comparison with non-electrostatic coating. Physical properties of the seasoning powders, adhesion, and coating evenness of the powders and the target foods (banana chips) were evaluated. It was found that particle size, ζ-potential and apparent density values of the seasoning powders varied depending on their types. In general, electrostatic coating enhanced coating performances as evidenced by high adhesion and coating evenness percentages. Coating of banana chips with sugar and mixed paprika flavor, both processes, provided greater adhesion and coating evenness than those of salt coating. Electrostatic voltages affected the adhesion and coating evenness, depending on seasoning types. Electrostatic coating influenced starch digestibility by either increased or retarded the digestion rate, depending on the quantities of seasonings adhered to the target foods.

Keywords: Electrostatic coating, Banana chip, Adhesion, Coating evenness, Image analysis

1. Introduction

Coating of seasoning powders is one of the most important steps for manufacturing of snack foods. Efficiencies of coating ensure sufficient adhesion between seasoning powders and the surface of snack foods. On the other hand, inefficient coating results in a poor distribution, seasoning falling off and consequently waste of the seasonings. Conventional coating procedures for snack foods may be done by batch or continuous processes. Batch process employs rotatable mix tanks for mixing the seasoning powders with snack foods. While continuous process may involve spraying of seasoning powders on the products carried by the conveyor. These conventional coating processes were found to cause insufficient adhesion and waste. Hence, the extra seasonings of 30-50% are normally added to the processes and that also added extra cost [1].

Modern coating process with high efficiency such as electrostatic powder coating was introduced. Initially, it has been used in automotive painting industry. More recently, it has been widely adopted by food industry. It produces even, uniform, and reproducible coatings with less waste compared to traditional coating processes. Electrostatic coating was found to reduce dust formation in the production lines and increase transfer efficiencies in snacks [2,3]. It has also been used as alternative method to liquid dipping for applying calcium powder to diced tomatoes [4]. It could also enhance efficacy of spraying antimicrobial agents in food products [5]. Therefore, this study aimed to compare the effects of electrostatic and non-electrostatic coating processes on coating qualities of unripe banana chips coated with various seasonings.

Electrostatic coating process starts with the charging of powder ingredients by an electric field. Due to similar charge, charged particles repel each other, forming an even cloud across the target surface [2]; at higher charge, the powder is more widely spread and has higher transfer efficiency [6]. Industrial applications of electrostatic coating can be used in combination with standard processing equipment for coating of various foods and powders.

Examples included grated cheese with antimycotic powders [2], potato chips with spices [7], popcorn with seasonings [3] and breads with cocoa powders [8].

Electrostatic coating process is normally evaluated by some physical properties such as transfer efficiencies and adhesion percentages. In addition, characterization of food products being produced by electrostatic coating process is important. There is still the need for new measurement techniques suitable for characterization of electrostatically coated food products. Image analysis with modern image processing software is promising as the fast, simple and non-destructive technique. It has been used for the measurement of evenness of the seasoning in potato chips [9]. Moreover, as most snack foods are rich is starchy carbohydrates, starch digestibility is one of the concerned properties. Modern starchy foods are required to exhibit less glycemic responses [10]. Hence, effects of electrostatic coating on starch digestibility of the coated food products were also examined. The information obtained from this study should be beneficial for both industry and academic uses.

2. Materials and methods

2.1 Raw materials

Mature green bananas, (*Musa* ABB cv. Kluai 'Namwa'), with fullness of the fingers (disappearance of angularity in a cross section) were obtained from Sukhothai province of Thailand. They were manually peeled by hands and immediately soaked in water to avoid exposure to the air, delaying enzymatic browning reaction. As soon as possible, peeled bananas were subject to longitudinal slicing using a knife to obtain the banana slices with about 2 mm thickness. Banana slices were then deep fried in palm olein oils using a 6 L electric deep fryer (LENODI, Thailand) for 5 min until their color became golden brown, frying temperature was set at 190°C, actual oil temperatures were 185-188°C. The straight deep-fried banana slices (not folded or broken) were selected and used immediately for seasoning powder coating experiments.

Seasoning powders used in this study were fine salt (Prung Thip Co., Ltd., Thailand), fine sugar (Mitr Phol Sugar Co., Ltd., Thailand) and a commercial mixed flavor (YUMMY brand, Chareunwai Intertrade Co., Ltd. Thailand). The commercial mixed flavor was paprika flavor. The major ingredients of the mixed flavor listed by the manufacturer are sugar, soy protein isolate, herbs and spices, monosodium glutamate, salt, artificial color and flavor.

All chemicals and enzymes used for starch digestibility were analytical grade purchased from Sigma-Aldrich (Thailand) Co., Ltd.

2.2 Electrostatic and non-electrostatic coating processes

Seasoning powders were coated using the lab-scale electrostatic coating equipment (Model TCCT918, TCCT Powder Coating Co., Ltd. China), employed the corona charging in which powder particles get charged during passing through an ion rich region. Then, powders were transported towards the target (banana chips) and deposited due to the charge difference, as illustrated in Figure 1. The coating equipment operates as a batch process, ensuring the same conditions were applied for all experimental treatments. Banana chips, about 50 pieces, were placed in the mixing chamber and the seasoning powders, 10 g per 100 g banana chips, were added to the powder chamber. In this study, three charging voltage settings (30, 40 and 50 kV) were applied with the same coating duration (5 s) and fixed air flow (5 m^3/h), following general conditions recommended by the machine manufacturer. Control samples were coated using the same electrostatic coating equipment without applying any charging voltage (0 kV). Air relative humidity was controlled at 65±2% and room temperature at approximately 25°C.

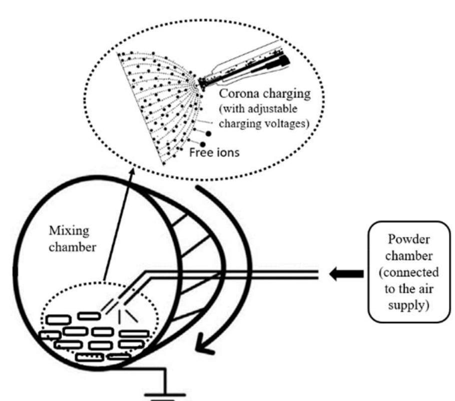

Figure 1 Illustration of the coating equipment.

2.3 Physical properties of the seasonings

Seasoning powders were examined for their particle size using the laser particle size analyzer (Mastersizer S, Malvern Instruments, UK). The electrophoretic mobility expressed as ζ-potential was determined using the zeta potential analyzer (HORIBA SZ-100-S, Japan), using ethanol as the dispersion medium. Apparent density was measured by dividing the mass and apparent volume (dimension method) of the seasoning powders.

2.4 Coating adhesion

The efficiencies of coating processes were determined by adhesion percentages. After coating, the banana slices were placed on the 1-mm sieve and shaken manually three times. They were weighed before and after coating as well as before and after shaking. The weight data were used to calculate adhesion percentages [11].

2.5 Coating evenness by image analysis

Coating evenness was indirectly examined by a simple image analysis technique [9,12] with some modifications. Briefly, pictures of banana chips were taken using a digital camera (1,024x768 pixels) at the same position for all samples. The image analysis software, ImageJ (National Institutes of Health, US) version 1.53f, was used for analyzing the obtained pictures. The percentages of coating evenness were quantified by the ratio of white areas to total areas in the pictures. At least ten pictures for each treatment were used for image analysis.

2.6 Starch digestibility

Total starch content of deep-fried banana chips before being coated with seasonings, as determined by the Total Starch (AA/AMG) Assay Kit (Megazyme Ltd., Ireland), was found to be 68.23±0.71 g/100g dry basis. Starch digestibility was examined by measuring the released glucose from enzymatic digestion of the samples using a glucometer [13]. Briefly, about 0.5 g of ground sample was weighted and treated with artificial saliva containing porcine α-amylase (Sigma A3176 Type VI-B) before pepsin (Sigma P6887; pH 2.0) was added and incubated at 37°C for 30 min in reciprocating water bath. The digesta was neutralized with NaOH before adjusting the pH to 6 (sodium acetate buffer) prior to the addition of pancreatin (Sigma P1750) and AMG (Novozymes AMG 300 L). The mixture was incubated for 2 h, during which the glucose concentration in the digesta (glucose released from the digested starch) was measured with Accu-Check® Performa® glucometer. The results were represented as a percentage of starch hydrolysis using the equation; starch hydrolysis (%) = Gr/Si x 0.9, where Gr is the amount of glucose released from starch digestion and Si is the initial amount of starch. A conversion factor of 0.9, the ratio of the molecular weight of the starch monomer to the molecular weight of glucose (162/180 = 0.9), was used [14].

2.7 Statistical analysis

Experimental data were analyzed using one-way analysis of variance (ANOVA) and expressed as mean values ± standard deviations unless specified otherwise. Tukey's method was conducted to examine significant differences among experimental mean values with a confidence level of 95%. Minitab® version 18 was used.

3. Results and discussion

3.1 Physical properties of the seasonings

Physical properties of all the seasoning powders as evaluated by the particle size distribution, ζ-potential and apparent density values are shown in Table 1.

Table 1 Particle size distribution, ζ-potential and apparent density values of the seasoning powders.

Seasoning powders	Particle size d50 (d10-d90) (μm)	ζ-potential (mV)	Apparent density (kg/m)
Salt	297.49b (182.38-430.72)	-3.73±1.35^{a}	1,320±4.1^{a}
Sugar	318.50a (190.68-464.08)	-11.17±0.06^{b}	620±0.1^{c}
Mixed paprika flavor	118.03c (19.80-263.87)	-29.83±2.74^{c}	670±0.3^{b}

Values are mean ± standard deviation (duplicate) except particle size.
Means with different letters within a column are significantly different ($p \leq 0.05$).

Particle size affects electrostatic coating performance, depending on the particle size range used. With smaller particles, electrostatic force dominates, and the smaller the particle, the more efficient the coating. However, with larger powders, gravitational force is more dominant than electrostatic force [15]. Particle sizes also influenced the charging capacities. In corona gun, particles can be charged by two mechanisms: field and diffusion charging, while the former being predominant charging mechanism. Due to the strong electric field produced by the corona discharge, the recommended particle size range for use with corona guns was 1-100 μm [16]. In this study, the particle size of the seasonings ranged from 116.12 to 302.56 μm, which was relatively large. They could only be charged by field charging as diffusion charging usually occurred with very small particle sizes (less than 0.2 μm) [16].

In terms of electrophoretic ability, all the seasonings showed initial negative ζ-potential values ranging from -29.83 to -3.73 mV. The values of the ζ-potential indicated dispersion behavior of the powders. Particles with ζ-potential between -30 to 30 mV were found to show tendency of coagulation [17]. Negative ζ-potential of the seasonings at the initial stage could alter the field charging of the particles by corona guns. Introducing particles with highly negative ζ-potential to the electric field of the corona guns might interfere free ions being adsorbed by the particles. The information in this matter is limited and there is the need for more research. Most previous research reported the charges produced on particles which related to their resistivity. It was found that as particle size decreased, the charge-to-mass ratio increased and that produced a greater radial trajectory, resulting in high coating performance as evidenced by more even and uniform dispersion [18].

For apparent density, as most food powders could fall within a small range of densities, density has little impact during electrostatic coating when compared to particle size or other factors [19]. Consequently, the apparent density of salt, although was higher than that of sugar and paprika, but they should not have much impact on the coating process. It has been proposed that electrostatic forces dominate over gravitational forces making density insignificant. Coulombic attractive forces exist between the charged powder particles and the target foods. These coulombic forces dominate as the charged particle moves closer to the target foods during the coating process [19].

3.2 Coating adhesion

Coating adhesion percentages of the seasoning powders in banana chips are shown in Figure 2. Generally, sugar and mixed paprika flavors tended to exhibit better adhesion than that of salt. High voltages also tended to show greater adhesion percentages, except in sugar coating.

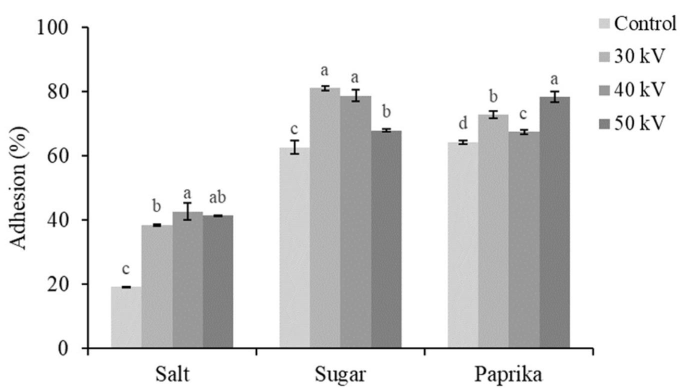

Figure 2 Coating adhesion percentages of seasoning powders in banana chips. Bars with different letters (within each seasoning) are significantly different ($p \leq 0.05$).

The target foods with low oil content and low resistivity exhibited the greater electrostatic adhesion when coated with high resistivity and small particle size seasoning powders at low relative humidity [11]. High voltage and increasing relative humidity during electrostatic coating process were also found to increase adhesion [1]. In this study, resistivity of seasoning powders could play a major role in controlling the adhesion. Salt which has been reported as a low resistivity (7.31 x 10^5 Ωm) [1] showed less adhesion percentages than those of sugar and paprika in all voltages applied (Figure 2). Sugar has been shown to exhibit high resistivity (2.3 x 10^{15} Ωm) [20]. Paprika flavor contains sugar as the main ingredient. Therefore, sugar and paprika showed similar adhesion performance.

In terms of voltages, the trend seemed inconsistent. It was obvious that electrostatic coating using all voltage levels (30-50 kV) exhibited greater adhesion than non-electrostatic coating. However, increasing voltage levels from 30-50 kV did not directly relate to the improved adhesion. The adhesion percentages of salt coating at 40 and 50 kV as well as sugar coating at 30 and 40 kV exhibited no statistical difference ($p>0.05$). Other factors could also influence the adhesion performance. It has been reported that adhesion force became stronger with increasing coating voltage, especially from medium voltage (40 kV) to high voltage (95 kV). Capillary force induced from high environmental relative humidity during coating also positively influenced coating performance [1]. Voltages applied in this study, 30-50 kV, could be too narrow to observe obvious changes. Voltages could interact with viscosity and that had the greatest effect on reproducibility of liquid electrostatic coating [21]. There is still the need for in-depth research on effects of voltages on electrostatic powder coating.

3.3 Coating evenness by image analysis

Even distribution of seasoning toppings is important to the appearance, taste, and quality of snacks. Insufficient adhesion could also result in the waste of seasonings and poor distribution of product's flavors [1]. This study demonstrated the use of a simple image analysis technique to evaluate the coating evenness in banana chips. The images of banana chips after coating were analyzed by the ImageJ software and the examples are shown in Figure 3. The white areas in the images could represent the areas at where they were covered by the seasonings. Their ratio to total areas could be used as numerical data for coating evenness and this is shown in Table 2.

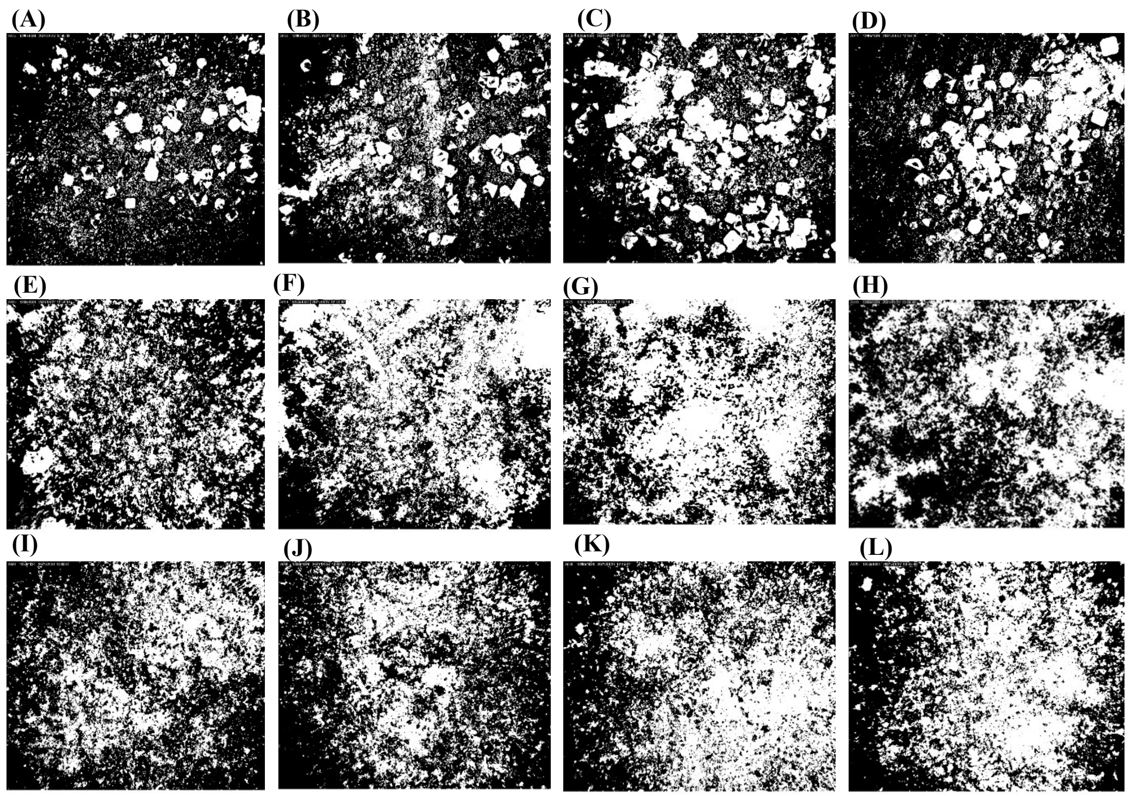

Figure 3 Images of banana chips after coating with seasonings and analyzed by image analysis software; (A) Salt (control), (B) Salt 30 kV, (C) Salt 40 kV, (D) Salt 50 kV, (E) Sugar (control), (F) Sugar 30 kV, (G) Sugar 40 kV, (H) Sugar 50 kV, (I) Paprika (control), (J) Paprika 30 kV, (K) Paprika 40 kV, (L) Paprika 50 kV.

Table 2 Coating evenness percentages (ratio of the white to total area) of banana chips coated with seasonings.

Seasoning powders	Coating evenness (%)			
	Control	30 kV	40 kV	50 kV
Salt	60.23±4.01d	78.96±4.15c	92.26±4.43a	83.91±5.87b
Sugar	136.22±2.45b	135.80±6.77b	139.67±0.90a	136.15±3.79b
Mixed paprika flavor	122.10±2.51c	126.08±2.14ab	124.18±3.25bc	126.90±2.24a

Values are mean ± standard deviation (ten images).
Means with different letters within a row are significantly different ($p \leq 0.05$).

From Table 2, electrostatic coating at all conditions significantly ($p \leq 0.05$) enhanced the coating evenness as evidenced by high ratios of the white to total areas, when compared to non-electrostatic coating. Sugar and mixed paprika flavor showed greater coating evenness than that of salt. Voltages also affected coating evenness, depending on seasoning types. Salt, sugar, and paprika flavor are best coated at different voltages; 40 kV for salt and sugar, while 50 kV for paprika (Table 2). Smaller particles, such as paprika flavor in this study, could pick up more charges during electrostatic coating due to their greater surface area to mass ratio. This resulted in a stronger particle attraction to the food targets, providing higher transfer efficiency and more uniform coating [7,22]. Sugar, in contrast to paprika, had the biggest particle size but provided great coating evenness. This could be influenced by high resistivity of sugar. For salt, it was smaller than sugar, but it exhibited low resistivity as discussed earlier. This could limit powder-target adhesion and consequently alter transfer efficiency and coating evenness.

Coating evenness could only be measured indirectly using several techniques. Previous research reported the determination of coating evenness by colorimetry or sensory techniques [9]. Samples with smaller standard deviation were considered as more evenly coated. These techniques have some limitations such as poor repeatability. Currently, image processing was proved to be the useful tool for quality grading of foods from the acquired images [9,12,23,24]. This research demonstrated the use of a simple image analysis technique to quantify the coating evenness in banana chips. This method is simple and fast. With the aid from modern image analysis software such as the open-source ImageJ, the technique could be applied to any food regardless of their color tones.

3.4 Starch digestibility

Starchy foods with less starch digestibility or low glycemic response are considered healthy. Banana chips are made of unripe bananas which contain considerably high amount of starch. Total starch content of banana chips in this study was found to be 68.23±0.71 g/100g dry basis. Unripe bananas are also considered as a rich source for healthy resistant starch [25]. Effects of electrostatic coating on starch digestibility of banana chips as illustrated by starch hydrolysis percentages are shown in Figure 4 (A-C).

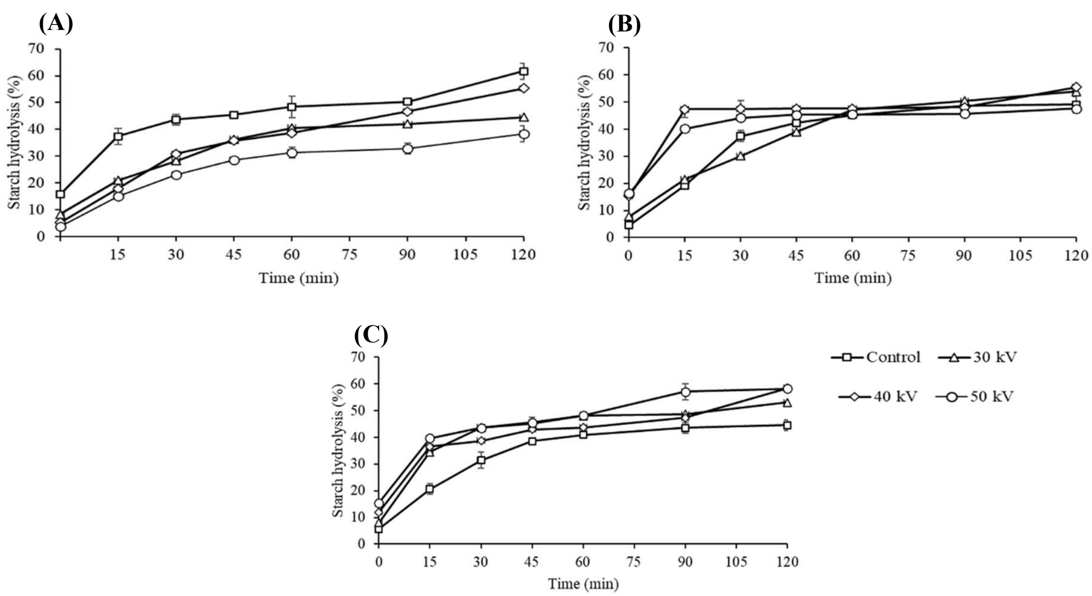

Figure 4 Starch hydrolysis percentages of banana chips coated with seasonings: salt (A), sugar (B) and mixed paprika flavor (C).

It can be seen that electrostatic coating at all voltage levels reduced starch digestibility rate in banana chips coated with salt (Figure 4A). The higher the voltage, the lower the starch digestibility rate. In case of salt, electrostatic coating enhanced the adhesion of salt to the target banana chips as shown earlier. Previous study suggested that salt and acids delayed starch digestion rate through several mechanisms [26]. In this study, high salt content in the mixture during in-vitro enzymatic digestion could manipulate the mixture viscosity and subsequently alter the enzyme actions, delay starch hydrolysis [27].

However, in sugar and paprika flavors, the trend was different. Electrostatic coating of banana chips with sugar and paprika increased starch digestibility and this was obvious in paprika Figure 4 (B-C). We hypothesized that seasoning types influenced the amount of glucose released during enzymatic digestion. The digestibility of starch was determined by determining the amount of glucose released during enzymatic digestion of the samples (banana chips coated with seasonings). Due to the high efficiency of electrostatic coating, more seasoning could have adhered to the chips. Sucrose is an ingredient in the mixed seasoning that acts as a substrate for enzymes in the in-vitro digestion system, resulting in a higher end product (glucose). The combination of glucose released from the enzymatic digestion of banana chips and sucrose (from seasonings) resulted in the high digestibility rate.

4. Conclusion

The food industry could benefit from a high-efficiency coating process such as electrostatic powder coating. In comparison to traditional coating processes, it produces even, uniform, and reproducible coatings. This study established that electrostatic coating improved the coating performance of banana chips that had been seasoned with a variety of seasonings. The image analysis technique has been shown to be a simple yet effective tool for determining the evenness of coatings. It should be noted that the amount of seasoning applied to foods had an effect on their properties, such as the starch digestibility of the banana chips examined in this study.

5. Acknowledgments

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