Effect of electrode voltage for NaCl coating on baked potato chips in continuous electrostatic coating system

Nutsuda Sumonsiri[1*], Prayoot Akkaraekthalin[2], Vilai Rungsardthong[1]

(1. *Department of Agro-Industrial, Food, and Environmental Technology, Faculty of Applied Science, King Mongkut's University of Technology North Bangkok, Bangkok 10800, Thailand*;
2. *Department of Electrical and Computer Engineering, Faculty of Engineering, King Mongkut's University of Technology North Bangkok, Bangkok 10800, Thailand*)

Abstract: Powder coating is an important process in the food industry, especially for snack foods such as potato chips, to create variety in food products. Electrostatic coating has been adopted in order to provide better transfer efficiency and lower the dust produced during coating. Studying the effect of electrode voltage on coating efficiency and evenness of baked potato chips using the developed electrostatic powder coating system was the main purpose of this research. Different types of NaCl (refined and table salts) were coated on baked potato chips at 0, 30, 40, 50, 60, and 70 kV. After coating with either refined or table salt, transfer efficiency, adhesion after coating, coating evenness and texture of samples were determined. Higher transfer efficiency, adhesion and coating evenness were observed when electrostatic coating was conducted at 30-50 kV. Most samples with higher transfer efficiency, adhesion and evenness were obtained after electrostatic coating. However, it did not significantly affect hardness of baked potato chips.

Keywords: electrostatic food powder coating, sodium chloride, adhesion, transfer efficiency, baked snack food
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1 Introduction

Potato is one of the most popular plants cultivated in many countries[1]. This crop is ranked at the fourth most important crop in the world after rice, wheat and maize[2]. It is usually used in the snack production, especially potato chips. In quality evaluation of snack foods, physical characteristics such as shape, color and texture, as well as flavor, are very important for consumer acceptability of the product[3]. Coating of dry seasoning powders on either fried or baked food products is one of the important value-added processes in snack food production. Salty snacks usually contain 1.5%-2.0% salt and 6%-12% total seasoning. The amount of salt or seasoning coated depends on flavor required, powder adhesion[4], coating method, and evenness of seasoning powders.

Electrostatic powder coating was initially developed in painting industry and then introduced in food industry in the 1960s to produce products with even coating since electrostatically charged powder particles tend to repel one another and disperse across the surface, rather remaining in the air[5]. Coating evenness shows how well food powder is dispersed on the target; therefore, it directly affects the appearance of food product and consumer acceptability[6]. High powder adhesion is also expected in the electrostatic coating because of the better attraction force of charged particles of powder on the surface of food target[7]. During processing, dust, powder build-up and overuse of food powders can be minimized by using electrostatic coating, therefore; the worker health issues and cleaning process can be reduced, resulting in lower operating costs[7,8].

In snack food seasoning processes, there are usually two types of coating systems: a coating system with tumble drum and a coating system with conveyor belt[9]. In the coating system with tumble drum, there is a rotating stainless-steel cylinder containing internal baffles for flipping food targets. These baffles improve the ability of the system to coat all sides of the food targets. To produce coated food, a gun, auger or vibratory feeder are used to charge and disperse food powder in the drum, resulting in a spray of charged food powder. This coating system is suitable to coat the food products which are not breakable easily. With appropriate conditions, all sides of the food targets can be evenly coated; however, this coating system cannot be used in a continuous production since the coating can be conducted based on a batch production. The conveyor belt coating system is the other coating system, which can be used in a continuous production. In this system, the food targets are placed on the grounded conveyor belt, made of metal or conducting plastic to attract the charged powder, which enters the system by using a gun, waterfall or pneumatic sprayer positioning over the conveyor belt. During coating, food powder is usually blown from a reservoir or powder feed hopper to a feed pipe and through a powder dispenser with an electrode to create the electrostatic field (Figure 1). Then, the charged powder enters the system and lands on the food target[5]. The targets on conveyor belt can be continuously moved for providing a continuous production; however, the targets are coated only one side, except that the special equipment to flip the target.

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Biographies: Prayoot Akkaraekthalin, PhD, Professor, research interest: antennas and propagation, microwave engineering, and RF engineering, Email: prayoot.a@eng.kmutnb.ac.th; **Vilai Rungsardthong,** DTechSc, Professor, research interest: food processing, food extrusion, starch chemistry and processing, and biocomposite, Email: vilai.r@sci.kmutnb.ac.th.
***Corresponding author: Nutsuda Sumonsiri,** PhD, Associate Professor, research interest: food processing, food powder coating, edible coating and film, King Mongkut's University of Technology North Bangkok, 1518 Pracharat 1 Road,Wongsawang, Bangsue, Bangkok 10800, Thailand. Tel: +66 2 555-2000 ext. 4705, Fax: +66 2 555-2000 ext. 4701, Email: nutsuda.s@sci.kmutnb.ac.th.

Another challenge for application of this coating system is the setup of the coating parameter, such as electrode voltage, powder flow rate, conveyor belt speed, and height of the powder feeder to eventually create the even products. Various powders and targets need different settings to create the highest coating performance and evenly coated food products while minimizing the consumption of food powder, leading to the economic production; therefore, the objective of this study was to develop the conveyor belt coating system for the continuous production and investigate the effect of electrode voltage on coating performance and physical properties of baked potato chips after coating.

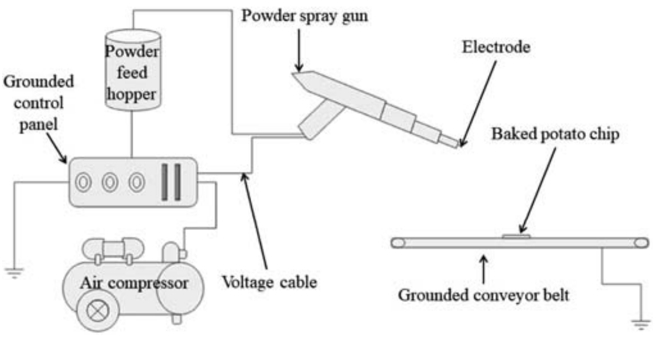


Figure 1 Illustration of electrostatic coating spray gun for experimental set-up

2 Material and methods

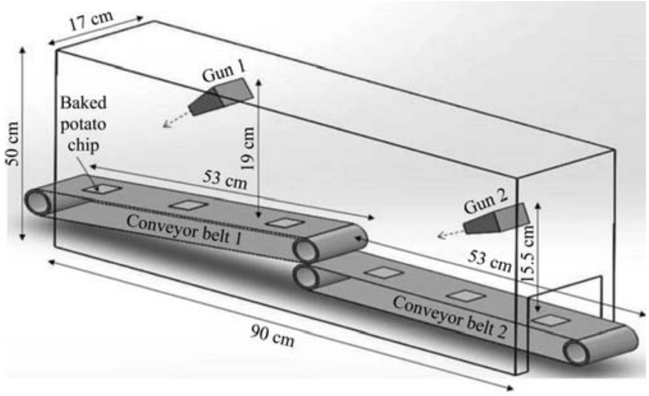
2.1 Materials

Refined salt (Prung Thip, Thai Refined Salt Co., Ltd, Nakornratchasima, Thailand) and table salt (Tesco, Hang Tat (1999) Ltd., Part., Bangkok, Thailand) were two different types of salts used in this research. They were stored in desiccators with desiccant for 3 d before coating.

The targets used in this study were prepared by peeling and slicing white potato into 2 mm thick using a potato slicer. Each potato slice was cut into a final square shape (5 cm×5 cm) using an aluminum square mold and then baked under convection heating in the preheated oven toaster (EOT4805K Electrolux oven toaster, Electrolux Thailand Co., Ltd., Rayong, Thailand) at 200°C±5°C for 15-20 min (until moisture content (by gravimetric method[10]) and a_w were 6%±1% (dry basis) and 0.40±0.02 respectively).

2.2 Electrostatic coating system set-up and coating conditions

The electrostatic powder coating system with conveyor belts was developed following the design in Figure 2. In this system, food sample was flipped by using 2 grounded conveyor belts (108Engineer, Pathumthani, Thailand). Therefore, both sides of food sample were coated by 2 electrostatic powder spray guns, connected to a powder feed hopper, grounded control panel (TCCT electrostatic powder coating test machine set, Tianchang Changtai Electronic Co., Ltd., Anhui, China), and air compressor (ETOP Oil-free air compressor, Zhejiang Shengli, Industry & Trade Co., Ltd., Zhejiang, China) as demonstrated in Figure 1. Each type of salt was coated onto baked potato chips at 0 kV (for nonelectrostatic coating), 30 kV, 40 kV, 50 kV, 60 kV, and 70 kV. The speed of conveyor belts was fixed at 15±1 cm/s and the capacity of coating on potato chips was 72±2 slices/min. The feed rate was controlled to achieve a coating level of 7.5%±1.0% by sample weight. The whole coating system was covered by clear acrylic; therefore, the processing was conducted in controlled environment to prevent contamination. The research was conducted at 25°C±5°C with 55%±5% RH. Coated potato chips were packaged in polyethylene bags and stored at room temperature. Transfer efficiency and adhesion were determined immediately after coating while coating evenness and texture were determined within 24 h after coating.



Note: Powder entered the chamber from the electrostatic powder spray guns 1 and 2 (at angles of 45° and 30° with the horizontal line, respectively) to land on the baked potato chips moving along 2 conveyor belts. Conveyor belt 1 was horizontally overlapped with conveyor belt 2 at an angle of 17° with the horizontal line to automatically flip the food sample.

Figure 2 Illustration of electrostatic coating system designed for this research

2.3 Coating performance

The transfer efficiency (TE) was calculated using the weight of the targets before and after coating following the equation:

$$\text{TE} = \frac{(\text{weight of coated potato chip} - \text{weight of potato chip prior to coating})}{(\text{weight of powder fed in the system})} \times 100 \tag{1}$$

After coating, the potato chips were shaken 20 times manually before determining the coating adhesion, which was calculated using the following equation:

$$\text{Adhesion} = \frac{(\text{weight of coated potato chip after shaking} - \text{weight of potato chip before coating})}{(\text{weight of coated potato chip} - \text{weight of potato chip before coating})} \times 100 \tag{2}$$

Coating evenness was indirectly determined using the color parameter b^* (yellowness or blueness) by Hunter colorimeter (Color Quest 45/0, Hunter Associates Laboratory, Inc., Reston, V.A., U.S.A.). Four quadrant positions per each side of sample were measured. The difference of b^* (Δb^*) between 2 sides of the sample and standard deviation (SD) among treatments were calculated and used to determine for coating evenness. Samples with lower Δb^* and SD were indicated as samples with more even coating.

A texture analyzer TA.XT2i (Stable Micro Systems Ltd., U.K.) was used to measure hardness of samples by applying force using a spherical stainless probe (P/0.25S) of ¼-inch diameter on a sample placing on the HDP/CFS (Crisp Fracture Support Rig and corresponding platform, SMS). The test settings were: pre-test speed 1.00 mm/s, test speed 2.00 mm/s, travel distance of the probe 5.0 mm, post-test speed 10.00 mm/s, trigger force 5.0 g.

2.4 Statistical analysis

Every analysis was conducted in triplicate and analysis of variance (ANOVA) with Duncan's multiple range test (DMRT) was used to analyze the data to determine significant differences (p<0.05) among averages using IBM SPSS Statistics 21 (IBM Corporation, Armonk, NY, USA).

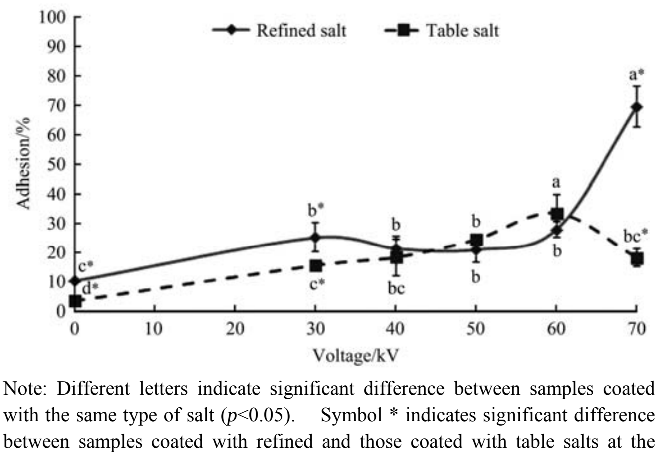
3 Results and discussion

3.1 Transfer efficiency

As presented in Figure 3, electrostatic coating with electrode voltage from 30 kV to 70 kV produced significantly higher transfer efficiency than nonelectrostatic coating (0 kV) with both refined and table salts on baked potato chips ($p<0.05$). During corona charging, the external electrical field between the electrode and the high potential at the end of the gun tip is induced by the charging voltage at the electrode, resulting in ionized air and ion wind. The powder particles passing the gun tip then pick up the ions, leading to the cloud of charged particles. These charged particles repel one another and become more dispersed at longer distance from the electrode before depositing on food targets[11]. Therefore, the powder particles under electrostatic coating are more dispersed and deposited on the target when compared to nonelectrostatic coating. Several authors also found better transfer efficiency when applying electrostatic coating of seasonings on food targets[7,11-14].

Transfer efficiency tended to increase when electrode voltage increased, except electrostatic coating of table salt at 70 kV, which was not significantly different from electrostatic coating at 30-50 kV ($p\geq0.05$). Electric fields and corona currents theoretically increase when higher voltages are applied[15]. Higher voltage creates higher electric fields, leading to repulsion forces between charged particles of powder and space charges; therefore, cloud of powder particles is eventually produced and more dispersed. Nevertheless, when the voltage is too high, back corona can occur and lead to the decrease of particle charge and lower efficiency of powder deposition[16]. During the corona coating of black polyurethane paint powder on a blank printed circuit board with surface coverage of copper at 0.2 mm thick, the authors also observed the increase of mass-to-surface ratio (ratio of powder particles deposited to corresponding surface area) when voltage increased from 30 to 60 kV but the decrease of mass-to-surface ratio at 90 kV[16].

Refined salt, which has smaller particle size than table salt, showed higher transfer efficiency than table salt during nonelectrostatic coating and electrostatic coating at 30 kV and 70 kV. Smaller particles usually stay in the air due to aerodynamic forces while larger salt particles deposit on the food target because of gravitational forces and their momentum[14]. When the electrostatic force is applied, the smaller particles tend to have higher charge-to-mass ratio, leading to higher coating efficiency[9]. Moreover, back corona is more likely to occur in coarse particles than the fine particles[16].



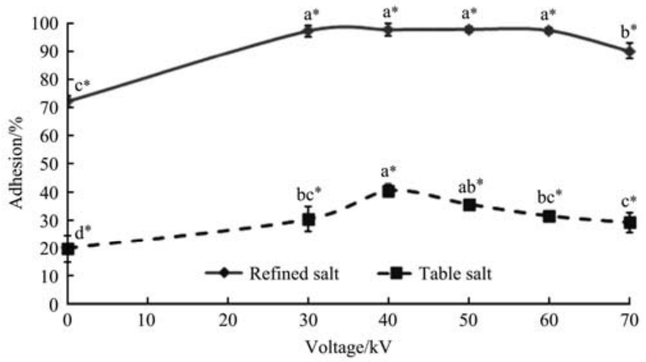
Note: Different letters indicate significant difference between samples coated with the same type of salt ($p<0.05$). Symbol * indicates significant difference between samples coated with refined and those coated with table salts at the same voltage ($p<0.05$).

Figure 3 Transfer efficiency of baked potato chips coated at 0-70 kV

3.2 Adhesion

Adhesion of powder particles on target surface is occurred by mechanical interlocking, solid bridges, capillary forces from liquid bridges, van der Waals force, electrostatic force, chemical force, hydrogen bonds, and diffusion[17]. Electrostatic coating with electrode voltage from 30 kV to 70 kV produced significantly higher adhesion than nonelectrostatic coating (0 kV) with both refined and table salts on baked potato chips ($p<0.05$) (Figure 4). The highest electrostatic adhesion obtained when the electrode voltages of 30-60 kV and 40-50 kV were applied for coating with refined salt and table salt on baked potato chips respectively. The increase of charging voltage leads to higher charge-to-mass ratio, resulting in higher electrostatic adhesive forces[11]. Electrostatic coating also increases adhesion by van der Waals force by compressing the surface asperities[9].

Refined salt produced significantly higher adhesion than table salt with or without electrostatic coating (Figure 4) ($p<0.05$). Larger particles produce lower adhesion since gravitational force dominates over electrostatic forces in larger particles. Therefore, they tend to fall off of the target easily[14]. Similar results were also found in the electrostatic coating on fried potato chips[12].



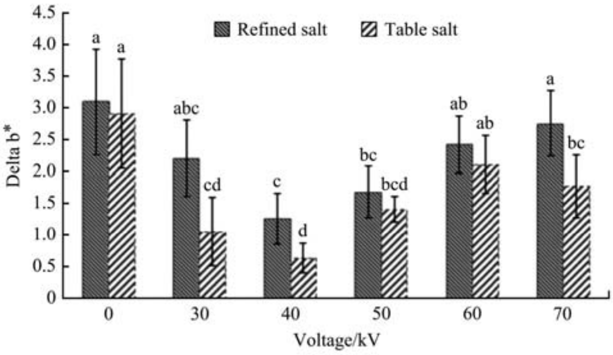
Note: Different letters indicate significant difference between samples coated with the same type of salt ($p<0.05$). Symbol * indicates significant difference between samples coated with refined and those coated with table salts at the same voltage ($p<0.05$).

Figure 4 Coating adhesion of baked potato chips coated at 0-70 kV

3.3 Coating evenness

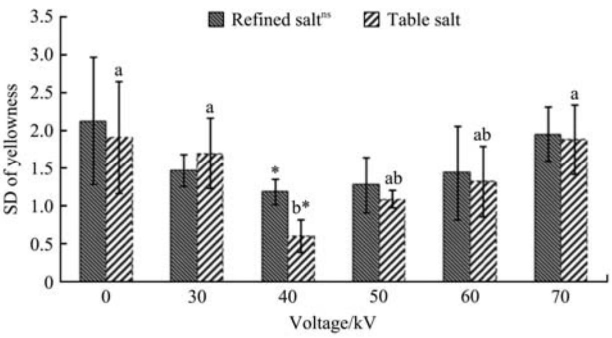
The coating evenness can influence the appearance and functionality of a coated product. During consumption, more even coated products are likely to have better distribution of flavor, leading to higher intensity and release of flavor[9]. Figures 5 represents differences of b* (Δb*) between each side of baked potato chips to indicate coating evenness on each piece of sample since each sample had been coated by the first gun before it was flipped and coated by the second gun (Figure 2). Electrostatic coatings with refined at 40-50 kV and table salts at 30-50 kV and at 70 kV produced significantly lower Δb* than nonelectrostatic coating ($p<0.05$). Figures 6 represents standard deviation (SD) of b* among treatments to indicate coating evenness among coated samples. There is no significant difference between coating evenness among samples when coating with refined salt. However, electrostatic coating at 40 kV produced significantly higher coating evenness than nonelectrostatic coating ($p<0.05$).

As discussed earlier in transfer efficiency, higher voltage provides higher currents and electric fields, resulting in repulsion between charged powder particles and space charges. This repulsion eventually produces more dispersed clouds[16], leading to more evenly coated targets. Another author also reported that electrostatic coating produced more evenly coated products than nonelectrostatic coating[11]. Nevertheless, electrostatic coating with too high voltage can create back corona and poor dispersion on a target, resulting in uneven coating[16].



Note: Different letters indicate significant difference between samples coated with the same type of salt (p<0.05).

Figure 5 Coating evenness between each side of baked potato chips coated at 0-70 kV

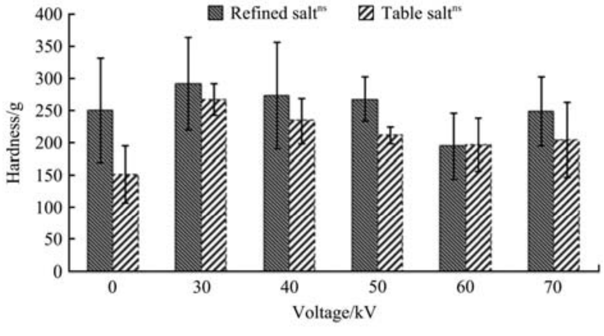


Note: Different letters indicate significant difference between samples coated with the same type of salt (p<0.05). Symbol * indicates significant difference between samples coated with refined and those coated with table salts at the same voltage (p<0.05). ns indicates that potato chips coated with the same type of salt were not significantly different (p≥0.05).

Figure 6 Coating evenness among baked potato chips coated at 0-70 kV

3.4 Texture

Hardness or the maximum force required to break baked potato chips coated at different charge voltage is presented in Figure 7. Electrostatic coating did not show any effects on hardness of baked potato chips coated with either refined or table salt. This may occur since moisture content and a_w of products were controlled to be 6%±1% (dry basis) and 0.40±0.02 respectively before coating and the analysis was conducted with 24 h after coating. The result can be used to indicate that electrostatic coating had significant effects on coating efficiency, adhesion and appearance of baked potato chips, but it did not affect the texture of the product as long as the products were processed and kept under the similar conditions.



Note: ns indicates that potato chips coated with the same type of salt were not significantly different (p≥0.05).

Figure 7 Hardness of baked potato chips coated at 0-70 kV

4 Conclusions

Higher transfer efficiency, adhesion and coating evenness can be obtained during electrostatic coating of both refined and table salts on baked potato chips at 30-50 kV. Most samples with electrostatic coating obtained higher transfer efficiency, adhesion and coating evenness than those samples with nonelectrostatic coating. However, it did not affect hardness of baked potato chips.

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