Sensory Preference, Coating Evenness, Dustiness, and Transfer Efficiency of Electrostatically Coated Potato Chips

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ABSTRACT: Barbeque, sour cream and onion, salt and vinegar, nacho cheese, and salsa seasonings were applied to potato chips at 0 and 25 kV. Sensory evaluation determined that electrostatically coated chips had better coating uniformity and were significantly preferred to nonelectrostatically coated samples. Electrostatic coating was also more even as measured by colorimetry. Particle size and evenness of coating did not significantly affect perceived flavor intensity. Electrostatic coating significantly increased transfer efficiency and decreased dust over nonelectrostatic coating. Particle size and flowability can be used to predict transfer efficiency and dustiness. Chargeability was also important for electrostatic transfer efficiency. Particle size was the most important factor overall.

Keywords: potato-chip seasonings, electrostatic coating, preference, dust reduction, transfer efficiency

Introduction

The objective of seasoning snacks is to apply seasonings in a uniform and consistent manner with the same appearance on both sides and an equal amount on each piece as a percentage by weight (Clark 1995; Hanify 2001). Most manufacturers over-apply seasoning to ensure an adequate amount on the snack; however, this still produces unequal coating on products and also causes more powder to be suspended in the air as dust (Pannell 1980). Excess seasoning falls off the product onto the processing line. Some seasonings, such as salt and vinegar, can have unpleasant odors for the operator. Continuously breathing high amounts of dust may cause respiratory distress, and dust is also an explosion hazard (Kauffman 1987). Sticky powder waste in the coating equipment area increases labor required for cleaning the system (Madl 2000). Poor seasoning distribution, over-use of seasonings, a sticky layer of seasoning, higher labor charges for cleaning, and powder dust are disadvantages of conventional coating (Clark 1995).

In electrostatic coating, powder particles fall through a corona zone where they pick up negative charges. Charged particles repel each other to form a uniform cloud and then seek the nearest object at ground potential. This results in an even coating of seasonings and less dust because powders seek the target object rather than stay suspended (Pannell 1980; Bailey 1998). Therefore, electrostatic coating compared with traditional coating gives higher transfer efficiency, more even coating, less seasoning usage, less seasoning waste, less cleanup time, less dust, and less chance of dust explosion (Pannell 1980; Bailey 1998).

The effect of seasonings' physical properties on electrostatic coating efficiency are important, but only a few articles are published using food. Miller and Barringer (2002) found that electrostatic coating is most beneficial in reducing waste and increasing coating efficiency when using small particles. However, they tested only salt. Ricks and others (2002) studied several food powders, finding an increase of 68% in coating efficiency and a decrease of 84% in dustiness when using electrostatic coating. However, none of the powders were potato chip seasonings, and they did not coat powders onto food items.

Particle size affects the rate of flavor compound release (Malone and others 2000). A small particle size increases surface area of a given weight and enhances flavor extraction of volatile compounds (Shahidi and Wanasundara 1998; Brauss and others 1999). In contrast, the shape of fat globules, rather than their diameter or surface area, was reported to have an impact on cheddar cheese flavor (Wijesundera and others 2000). Thus it is unclear whether particle size will affect flavor intensity on potato chips.

Large particles tend to fall off or result in uneven distribution (Seighman 2001), and unevenly coated seasonings result in poor flavor distribution (Clark 1995). Though electrostatic coating produces more even coating, no sensory evaluation on electrostatically coated food has been done. Whether the consumer can detect the difference between electrostatically and nonelectrostatically coated samples, or which they prefer, is unknown.

Despite numerous studies on electrostatic coating improving coating efficiency in non-food applications, there is no information on how the physical properties of common seasonings affect coating efficiency. This information is necessary to predict the coating improvement and reduction in dust that will be achieved using electrostatic coating. Our objectives were to determine whether there is a preference for nonelectrostatic or electrostatic coated potato chips, what drives any acceptance differences, whether size has an effect on flavor intensity, and predict how seasoning physical properties affect transfer efficiency and dustiness when using electrostatic coating.

Materials and Methods

The powdered snack seasonings used were barbeque (BBQ), sour cream and onion (SCO) (McCormick Research and Development, Hunt Valley, Md., U.S.A.), salt and vinegar (SV), salsa (SS), and nacho cheese (NC) (Kerry Inc., Beloit, Wis., U.S.A.). All seasonings were applied to unsalted potato chips (Mike-sell's Inc, Dayton, Ohio, U.S.A.) using a belt conveyor electrostatic powder applicator (Terronics Development Corporation, Elwood, Ind., U.S.A.) at 0 and 25 kV for nonelectrostatically and electrostatically coated potato chips, respectively. Seasoning is pneumatically conveyed through a corona zone, picking up a negative charge, causing it to seek the nearest ground, which was the potato chip. Feed rate and conveyor belt speed were controlled for each seasoning to achieve a coating level of 7.5 ± 1.0% by weight. A coating weight of 7.5% was chosen because it is a typical coating level used in industry.

The minimum detectable difference in coating level was determined by sensory evaluation. Forty panelists performed triangle tests on potato chips electrostatically coated with coating levels, which differed by 1% to 4%. The minimum detectable coating level difference was determined ($\alpha = 0.05$).

For each seasoning, at least 40 untrained panelists assessed both electrostatically coated and nonelectrostatically coated potato chips using a paired preference test (with 2 replicates), relative to ideal test (using a 5-point just-right scale), and triangle test (with 4 replicates). Panelists evaluated at least 2 sets of samples in each test to calculate the overdispersion. Panelists were screened to ensure they had consumed seasoned potato chips within the past 3 mo. Each sample was given a 3-digit code and was randomly served to avoid bias. In the relative to ideal test, panelists rated electrostatically coated and nonelectrostatically coated potato chips on a 5-point just-about-right scale for coating uniformity, flavor intensity, and crispness. For each attribute, the scale was labeled: not nearly enough (NNE), slightly not enough (SNE), just about right (JAR), slightly too much (STM), and much too much (MTM). For the triangle test, panelists visually evaluated potato chip samples to determine if differences between electrostatically and nonelectrostatically coated chips existed.

Nacho cheese was selected for further study of the effect of particle size on flavor intensity. Nacho cheese was ground to reduce its particle size by using an ultra centrifugal mill, Retsch ZM100 (Glen-Mills Inc., Clifton, N.J., U.S.A.). Both small (31 μm) and large (127 μm) nacho cheese powders were electrostatically coated onto potato chips. The 2-AFC (Alternative Forced Choice) test was conducted with 2 replicates. Thirty-two panelists assessed 2 chips and were asked to select which had more intense nacho cheese flavor.

Coating evenness was measured by a Minolta colorimeter model CR-300 (Minolta Co., Ramsey, N.J., U.S.A.). This method indirectly determined coating evenness using the color parameter yellowness to blueness (b). Color was measured in 4 quadrant positions per chip on 5 chips. Mean and standard deviation were used to determine whether electrostatically and nonelectrostatically coated samples were significant different in terms of coating evenness. Samples with smaller standard deviation were considered as more evenly coated.

Particle size (mm) was determined by Fraunhofer method for dry module using Coulter LS 130 particle characterization (Coulter Co., Miami, Fla., U.S.A.). Powder chargeability on each seasoning was measured by the amount of powder that adhered to aluminum foil after coating and hanging vertically for 20 min using a method adapted by Ricks and others (2002). Angle of repose was determined by the fixed-base method. Seasoning (100 g) was sifted by a powder sifter through a funnel with its tip 11 cm from the base of the collection dish (8.85-cm dia; 1.40 cm tall). The Hausner ratio is the ratio of the bulk densities of the tapped and the loosely packed (untapped) seasonings. Tapped bulk density was determined by reading the volume after 1250 taps of the 250-mL cylinder by the Vanderkamp tap density tester (Van-KEL Industries, Inc., Chatham, N.J., U.S.A.).

Transfer efficiency of each seasoning was measured by coating seasonings onto potato chips or an aluminum foil sheet at 0 and 25 kV for nonelectrostatic and electrostatic coating. The feed rate and conveyor belt speed used were 15 g/min and 1.8 cm/s, respectively. Each chip or sheet was weighed before and after coating.

Dustiness was determined at 0 and 25 kV for nonelectrostatic and electrostatic coatings. A cassette/PVC filter (SKC, Inc., Eighty Four, Pa., U.S.A.) was placed at the chamber outlet to collect dust by pumping air into the filter at a rate of 5 L/min by a model HFS 513A Gilian portable air sampling pump (Sensidyne, Wayne, N.J., U.S.A.) for 3 min. Filters were weighed before and after coating.

All physical properties, coating improvement, and dust were measured in triplicate, and the coating evenness was measured in 5 replications. All statistical analyses were performed by JMP software version 4.3 (SAS Institute Inc., Cary, N.C., U.S.A.). Student's t-test was used for determining whether coating efficiency, dust reduction, or coating evenness were significantly improved when electrostatic coating was applied. Standard least square regression analysis with effect screening was used to determine the effect of seasoning physical properties on coating efficiency and dustiness. Each model is statistically significant ($P < 0.05$). Variables in each model that were not statistically significant ($P > 0.05$) were excluded from the regression models. Preference, triangle, and 2-AFC data were analyzed using beta-binomial and binomial models and a combination of a probabilistic model and Chi-square were used to evaluate relative to ideal test results (Ennis and Bi 1998).

Results and Discussion

Sensory evaluation and coating evenness of potato chips

As determined by triangle tests, there was a significant difference between potato chips that differed by 3% ($P = 0.004$) or 4% ($P = 0.003$) coating level, but not 1% ($P = 0.961$) or 2% ($P = 0.607$). Thus, the minimum detectable coating level difference was 3%, and only potato chips coated in the range of 7.5 ± 1% were used for further sensory evaluation.

Panelists evaluated seasoning coated potato chips by various sensory evaluation methods (Table 1). For all 4 seasonings, electrostatically coated potato chips were significantly preferred to nonelectrostatically coated samples.

Next, to pinpoint the reason electrostatically coated chips were preferred, subjects were asked to rate how close to the ideal were the levels of each attribute. Panelists assessed coating uniformity, flavor intensity, and crispness, which were selected as the representative attribute in the areas of appearance, flavor, and texture (Table 1). For coating uniformity, electrostatically coated samples of all 4 seasonings, and 2 of the nonelectrostatically coated samples, did not differ significantly from ideal values. However, when comparing the 2 methods, electrostatically coated chips had a significantly more acceptable uniformity of coating than nonelectrostatically coated samples for all seasonings except sour cream and onion.

For both flavor intensity and crispness, no significant differences were found between the 2 coating methods (Table 1). Crispness was in fact identical for all samples and was used as a way to check the accuracy of the panelists since it was not affected by the coating procedure. For flavor intensity, there has been some work suggesting more even coating results in a perception of greater flavor intensity. More even coating covers a larger surface area for flavor distribution, which may enhance flavor release, resulting in greater flavor intensity (Clark 1995; Brauss and others 1999; Seighman 2001). However, this phenomenon was not found in this study. Of the 3 attributes examined, it appears that the visual uniformity of coating contributes most to the observed difference in preference between the samples.

It is not clear why coating uniformity of sour cream and onion coated electrostatically and nonelectrostatically had no difference in acceptability. For seasonings that are both easy to see (barbeque) and hard to see (salt and vinegar) significant differences were found between coating methods. The reason may be because sour cream

Table 1—Comparison of electrostatically (E) and nonelectrostatically (NE) coated potato chips by sensory analysis

Sensory technique	Potato chip seasonings			
	BBQ	SCO	SV	NC
Paired Preference Test				
E over NE	**	**	**	**
Gamma (g) value	0.307	0.300	0.000	0.000
Relative to ideal test				
a. Coating Uniformity				
Ideal mean value	0^{ab}	0^{a}	0^{a}	0^{a}
NE mean value	-0.868^{a}	-0.228^{a}	-1.60^{b}	-3.21^{b}
E mean value	0.070^{b}	-0.040^{a}	-0.389^{a}	-1.27^{a}
b. Flavor intensity				
Ideal mean value	0^{a}	0^{a}	0^{a}	0^{a}
NE mean value	0.214^{a}	0.126^{a}	-0.158^{a}	-1.02^{a}
E mean value	0.614^{a}	0.360^{a}	-0.414^{a}	-0.670^{a}
c. Crispness				
Ideal mean value	0^{a}	0^{a}	0^{a}	0^{a}
NE mean value	-0.735^{a}	-0.134^{a}	-0.333^{a}	-0.116^{a}
E mean value	-1.02^{a}	0.034^{a}	-0.358^{a}	-0.551^{a}
Visual Triangle Test				
E compared to NE	***	***	***	***
Gamma (γ) value	0.000	0.000	0.000	0.000

** and *** indicate significantly different at α = 0.01 and 0.001, respectively.
Values with a different letter are significantly different at α = 0.05.
0 is the mean score of the JAR scale, negative values mean not enough, whereas positive values mean too much.

and onion contains large green onion flakes (2 to 4 mm). Particle size plays an important role in electrostatic coating efficiency. Smaller particles have a greater surface area to mass ratio, which allows them to pick up more charge for their mass, resulting in a stronger particle attraction to the grounded target (Sandor 1990; Mazumder and others 1997; Bailey 1998). Thus, small particles produce higher transfer efficiency and more uniform coating when electrostatic coating is applied (Mazumder 1997; Bailey 1998). However, the green onion flakes may be too large for electrostatic coating to significantly improve coating uniformity. They may not be able to pick up enough charge to overcome gravity, resulting in uneven coating. The consumer may have judged evenness mainly on the green flakes and not the white powder. Different results might be observed if the size of the onion flakes were reduced.

To confirm that there is a difference in evenness of coating between electrostatically and nonelectrostatically coated chips, panelists performed a visual-only triangle test and were asked to distinguish samples based on overall appearance. For all 4 seasonings, electrostatically coated potato chips were significantly different from nonelectrostatically coated samples (Table 1).

An instrumental method for measuring coating evenness of potato chip samples was developed using the standard deviation of the b value measured at different locations on the chip. Yellowness (b value) was chosen because the majority of seasonings and potato chips are yellowish. For barbeque and nacho cheese, the larger the b value (yellowness), the more seasoning is present. However, for salt and vinegar and sour cream and onion, the yellow color comes from the potato chip, and the smaller the b value, the more seasoning is present. Based on b values, electrostatically coated samples had smaller standard deviations, or were more evenly coated, than nonelectrostatically coated samples for all seasonings except sour cream and onion (Figure 1). The colorimeter results matched well with sensory results. Electrostatically coated chips, based on the relative to ideal test, were also significantly more even than nonelectrostatically coated samples for all seasonings except sour cream and onion (Table 1). For sour cream and onion, the green color from the onion flakes may have caused no difference in coating evenness.

Particle size may have an effect on flavor release of seasoning compounds (Malone and others 2000). The smaller the particle, the greater the surface area for the extraction of flavor compounds, resulting in more intense flavor release (Shahidi and Wanasundara 1998; Brauss and others 1999). Thus, a study on different nacho cheese particle sizes was conducted to determine the effect of particle size on flavor intensity. However, there was no significant difference in flavor intensity between smaller (31 μm) and larger (127 μm) particle sizes of nacho cheese. Although smaller particle size and more even coating has been claimed to give more intense flavor, the phenomenon was not found in this study.

The effect of physical properties on nonelectrostatic coating transfer efficiency

Transfer efficiency (TE) is the amount of powder deposited onto the target in a coating system. Each seasoning had 2 different particle sizes. The physical properties of the seasonings were measured (Table 2) and used to predict the transfer efficiency and dustiness for nonelectrostatic coating and percent improvement when electrostatic coating is used (Table 3).

Size (S) and flowability, as measured by angle of repose (AR) and Hausner ratio (HR), significantly influenced the nonelectrostatic transfer efficiency. Similar equations were produced whether the coating was onto aluminum foil (Eq. 1) or potato chips (Eq. 2).

$$\text{TE on foil} = 35.3 + 0.00407\ S - 0.837\ AR + 0.610\ HR \times AR - 25.3\ HR \qquad R^2 = 0.751 \tag{1}$$

$$\text{TE on chips} = 34.4 + 0.00297\ S - 0.818\ AR + 0.591\ HR \times AR - 24.5\ HR \qquad R^2 = 0.695 \tag{2}$$

The prediction models for both aluminum foil and potato chips were similar for all transfer efficiency and dust tests. The same variables were important and the coefficient values and R^2 were close in all pairs. Hence, only prediction models for potato chips are shown in the rest of the article.

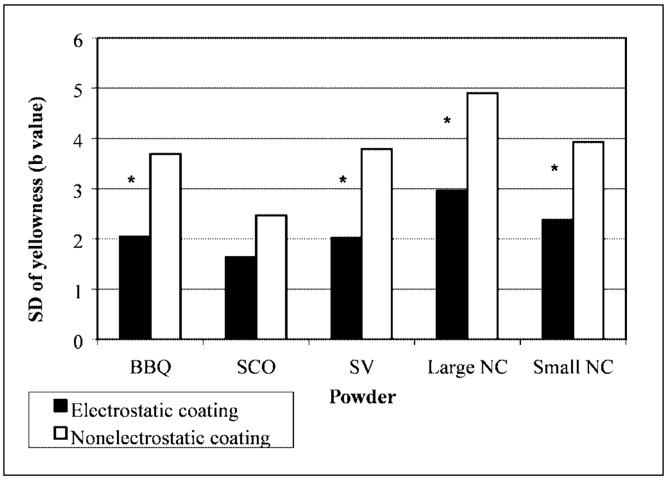

Figure 1—Coating evenness using standard deviations of yellowness of various seasonings. *Electrostatically coated potato chips were significantly more evenly coated than nonelectrostatically coated samples (P < 0.05).

Table 2—Powder properties of seasoning powders

Powder	Size (μm)	Powder charge (0 kV) (%)	Powder charge (25 kV) (%)	Angle of repose (degree)	Hausner ratio
Large BBQ	167	24.7	53.1	55.12	1.437
Small BBQ	25.7	20.8	60.7	53.54	1.369
Large SCO	122	18.5	43.7	33.46	1.302
Small SCO	92	22.2	39.0	53.08	1.415
Large SV	331	29.2	67.2	38.24	1.339
Small SV	184	27.0	74.5	36.95	1.276
Large NC	127	37.2	36.5	52.51	1.326
Small NC	31.3	20.0	63.1	50.14	1.394
SS	108	21.1	54.4	40.26	1.294

BBQ, SCO, SV, NC, and SS were barbeque, sour cream and onion, salt and vinegar, nacho cheese, and salsa, respectively.

Particle size was the most significant factor in explaining nonelectrostatic transfer efficiency. As the particle size increased, the nonelectrostatic transfer efficiency increased (Table 3). Larger particles fall onto the target by gravity rather than remaining suspended as dust while smaller particles tend to remain airborne, resulting in lower transfer efficiency and more dust (Table 2). This trend was also found by Ricks and others (2002), but it was opposite to that of Miller and Barringer (2002). However, Miller and Barringer (2002) studied only large salt particles, which were not dusty, and their coating system produced less dust in general.

Flow characteristics can be measured in several ways including angle of repose and Hausner ratio. They measure how free flowing the powder is or how likely it is to clump. Angle of repose is more dependent on cohesive forces than frictional force (Peleg 1977). Powders with angle of repose in the ranges of 35° to 45°, 45° to 60°, and > 60° are free flowing, fairly free flowing, and cohesive, respectively (Peleg 1977; deJong and others 1999). When the angle of repose is high, the seasoning is more cohesive because the particle forces at the interparticle contacts are significant compared to the force of gravity (deJong and others 1999).

As the angle of repose decreased, powder became more free flowing, and nonelectrostatic transfer efficiency increased. This effect was also reported by Ricks and others (2002). A high angle of repose value indicates the powder is cohesive and adheres to itself, creating powder clumps. Cohesive powder tends to settle rather than remaining suspended in the air; however, the clumps may have enough momentum to roll off the potato chips, resulting in less powder deposition on the target. This was observed visually. Large clumpy powders also have more difficulty adhering to food, resulting in lower transfer efficiency (Sieghman 2001). Finally, the more cohesive the powder, the more sticky build-up was observed on the conveyor belt and machine parts.

Hausner ratio is dependent on frictional forces of the powder particles (Peleg 1977). It similarly indicates how free flowing or how clumpy the powder is when powder is in the loosely packed state. Seasonings with a Hausner ratio in the range of 1 to 1.25, 1.25 to 1.4, and >1.4 are free flowing, fairly free flowing, and cohesive, respectively (deJong and others 1999). The higher the Hausner ratio, the more cohesive the seasoning. As Hausner ratio decreased or powders became less cohesive, nonelectrostatic coating increased, the same as for angle of repose.

Effect of physical properties on electrostatic transfer efficiency improvement

Percent coating improvement when electrostatic coating was used was calculated from the transfer efficiency values at 25 kV minus 0 kV divided by 0 kV. When using electrostatic coating, the transfer efficiency was significantly improved for all seasonings. The coating improvement ranged from 25.4% to 114% with an average of 64%, indicating that electrostatic transfer efficiency was almost double that of nonelectrostatic (Table 3). The small nacho cheese gave the greatest coating improvement whereas large salt and vinegar had the least coating improvement. The powder properties significantly affecting the coating improvement, from the most to least significant, were size (S), powder charge (C), and angle of repose (AR) (Eq. 3).

$$\text{Percent coating improvement on chips} = 21.3 - 0.235\,S + 0.663\,C + 0.661\,AR \quad R^2 = 0.862 \qquad (3)$$

Size was the most significant effect contributing to the variability of the data. Smaller particles resulted in greater coating efficiency improvement than larger particles. A similar effect of size on electrostatic coating efficiency was reported by Miller and Barringer (2002) and Ricks and others (2002). In contrast, this trend was opposite to the effect of size on nonelectrostatic coating transfer efficiency.

Small particles have a larger surface area so they typically develop more charge compared with their mass (Mazumder and others 1997; Bailey 1998). This results in an improvement in electrostatic coating with increased particle deposition and better adherence to the surface by electrostatic force (Sandor 1990; Mazumder and others 1997; Bailey 1998). In general, small particles have low inertia, are affected less by gravity, and so are more vulnerable to course alterations from electrostatic force. Smaller particles typically develop higher charge (Mazumder and others 1997), causing powders to repel each other and seek the target instead of remaining airborne as dust. On the other hand, large particle sizes do not develop a high charge so gravitational force is predominant, resulting in less coating improvement (Sandor 1990; Mazumder and others 1997; Bailey 1998).

Powder chargeability is a measure of how much charge the powder has acquired and the rate of charge decay. Powder chargeability was also a significant contributor to the improvement in electrostatic coating efficacy. The greater the powder chargeability, the greater the electrostatic coating transfer efficiency improvement. Charged powders repel each other in the corona zone and seek to deposit on the target, resulting in higher transfer efficiency and less dust. The increase in electrostatic coating efficiency with an increase in powder charge was similar to the result of Miller and Barringer (2002). However, charge was unexpectedly not reported to be significantly important by Ricks and others (2002). The one obvious outlier was salt and vinegar, which had a low coating improvement although it had a high chargeability. The low transfer efficiency for salt and vinegar may have been due to the effect of large particle size.

The flowability measurement, which was a significant contributor to electrostatic coating improvement, was angle of repose. The trend was opposite to that of nonelectrostatic coating. An increase in angle of repose, or the powders becoming more cohesive, increased electrostatic coating efficiency. This phenomenon was similar to the one reported by Ricks and others (2002). The charge developed on the particles may cause the particles to repel each other and break up the clumps. This would effectively decrease particle size, resulting in higher coating efficiency. The powder clumps would otherwise miss the target or roll off the conveyor belt as observed in nonelectrostatic coating. Therefore, electrostatic coating is especially valuable for cohesive powders. The largest improvement was observed in barbeque and small nacho cheese, which

Table 3—Nonelectrostatic coating, transfer efficiency improvement, and dustiness results for all powders.

Powder	Nonelectrostatic coating (g)		Coating improvement at 25 kV (%)		Nonelectrostatic dustiness (mg/L)		Dust reduction improvement at 25 kV (%)	
	Al foil	Chips	Al foil	Chips	Al foil	Chips	Al foil	Chips
Large BBQ	1.82	1.61	62.0*	50.8*	0.342	0.117	49.3*	49.7*
Small BBQ	1.38	1.04	98.8*	92.8*	0.356	0.059	58.5*	46.1*
Large SCO	1.35	1.15	54.7*	49.5*	1.55	0.030	41.8*	36.5*
Small SCO	1.38	0.760	52.3*	45.7*	0.640	0.027	40.9*	32.6*
Large SV	2.07	1.52	25.4*	19.8*	0.267	0.027	16.7	9.92
Small SV	0.470	1.41	49.8*	43.6*	0.964	0.070	20.9*	14.1*
Large NC	1.61	0.480	65.6*	58.0*	1.65	0.110	32.5*	27.9*
Small NC	0.667	0.387	114*	99.9*	1.73	0.131	58.3*	52.6*
SS	1.32	1.17	56.8*	51.7*	1.01	0.074	41.4*	35.2*

Significant improvement of electrostatic coating over nonelectrostatic coating ($P < 0.05$)

were the most cohesive of the powders as well as the smallest. Sour cream and onion and salt and vinegar, which were the most free flowing of the powders, showed the least improvement with electrostatic coating. However, they also had the largest particle sizes.

The effect of physical properties on nonelectrostatic dustiness

The physical properties that significantly influenced nonelectrostatic dustiness were size and flowability (Eq. 4).

$$\text{Nonelectrostatic dust} = -0.689 - 0.00512S + 0.246\,AR - 0.143\,HR \times AR \quad R^2 = 0.557 \quad (4)$$

Size was the most significant contributor to nonelectrostatic coating dustiness. The smaller the particle size, the more dusty the environment. This result was expected. Large particles do not create as much dust during coating because of their mass. Fine powders remain airborne as dust rather than depositing onto the target, whereas larger particle size powders tended to fall down onto the target or conveyor belt by gravity instead of remaining airborne, resulting in a less dusty environment.

Flowability also significantly affects nonelectrostatic dustiness. As the powders became more cohesive, dustiness increased. This is unexpected, but in this case particle size may play an important role. The cohesive seasonings used in this experiment had a small particle size, and smaller particles generally create more dust. This result was also opposite to that of Ricks and others (2002) who suggested that cohesive powders have an effective increase in mass and size from particles adhering to each other and therefore are less dusty.

The effect of physical properties on electrostatic dust reduction

Electrostatic coating significantly reduced the dust produced by the process compared with nonelectrostatic coating for all seasonings except large-size salt and vinegar. The percent dust reduction ranged from 16.7% to 58.5% with an average of 40%. The factors affecting dust reduction were size (S) and Hausner ratio (HR) (Eq. 5). Small-size nacho cheese and barbeque showed the greatest dust reduction, whereas salt and vinegar had the least dust reduction.

$$\text{Percent dust reduction} = -70.4 - 0.0863\,S + 86.5\,HR \quad R^2 = 0.728 \quad (5)$$

Size was the most important contributor to dust reduction with electrostatic coating. As the size decreased, electrostatic coating was more efficient at reducing dust for the same reasons as for electrostatic coating transfer efficiency improvement. This observation was similar to the trend reported by Ricks and others (2002), although their data was not sensitive enough to predict an actual model for electrostatic dust reduction.

Flowability (Hausner ratio) was also a significant factor. More cohesive powders had a greater reduction in dust with electrostatics, similar to the results for electrostatic transfer efficiency.

Powder chargeability was not a significant contributor in explaining electrostatic dust reduction. This was unexpected because chargeability has been reported as an important factor for electrostatic coating (Mazumder and others 1997); however, either is it not important to dustiness or the measurement method used was not sensitive enough.

Conclusions

Electrostatically coated chips were significantly different from and significantly preferred over nonelectrostatically coated. They were also judged significantly more uniform in appearance, thus visual coating uniformity is likely to be more important to consumer preference than either crispness or flavor intensity. Coating uniformity measured by the standard deviations of b value correlated well with sensory results.

For nonelectrostatic coating, as size increases, the coating efficiency increases with decreasing dust. The more cohesive the powders, the lower the coating efficiency and dust. For electrostatic coating, the smaller or more cohesive the powder, the greater the increase in coating improvement and dust reduction. An increase in powder charge increases percent coating improvement.

Since electrostatic coating results in a higher transfer efficiency and reduction in dust that is likely to produce less wasted seasonings, less labor is needed for cleaning and this therefore results in more preferable chips at a lower cost.

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