IMPROVED FUNCTIONALITY OF FOOD ADDITIVES WITH ELECTROSTATIC
COATING

A Thesis

Presented in Partial Fulfillment of the Requirements for
the Degree Master of Science in the
Graduate School of The Ohio State University

By

Akou Enyonam Amefia, B.S.

The Ohio State University

2005

Master's Examination Committee:

Dr. Sheryl A. Barringer, Adviser

Dr. John Litchfield

Dr. Michael E Mangino

Approved by

Adviser

Food Science and Nutrition Graduate Program

ABSTRACT

Electrostatics is widely used in the snack food industry as an alternative to traditional powder coating. The purpose of this study is to determine whether electrostatics improves the functionality of different food powders and to evaluate the mechanisms involved in the process. French fries were coated at 0kV and -25kV with smoke extract or glucose and mozzarella cheese slices with sodium erythorbate or cellulose with natamycin. French fries were evaluated based on color and the cheese slices were evaluated on appearance of mold. Transfer efficiency was higher for all electrostatically coated products except for powdered cellulose on cheese. This effect was removed by comparing samples that had the same amount of powder. Electrostatically coated samples showed a greater color development and less mold growth than nonelectrostatically coated samples for the same amount of powder. This improvement in color and shelf life could be explained by improvement in evenness. Charge to mass ratio was larger for all powders electrostatically charged except cellulose. The particle size, flowability and size distribution may also contribute to the efficiency of the electrostatic coating. Small, free flowing powders with narrow size distribution showed the biggest improvement in color and shelf life while large, cohesive powders with wide size distribution had the least. Powder mixtures with flow agents or that have

the tendency to tribocharge during transportation have decreased overall charge received by the powder particles. Cellulose with natamycin did not show an improvement in transfer efficiency, mold suppression or charge to mass ratio with electrostatic coating.

DEDICATION

Dedicated to my parents Yao and Akuvi Amefia

My brothers Anani, Assa, Koffi, Komi, Michou

My sister Delali and all my friends.

Without their support I would not be here today.

ACKNOWLEDGEMENTS

I could not have done this without God's blessings and grace.

I wish to thank my adviser, Dr. Sheryl Barringer for believing in me and giving me the chance to come back to school. Her patience, expertise, encouragement and support are greatly appreciated. Her guidance is very important for the completion of this thesis.

I want to thank my committee members, Dr Mangino, Dr Min and Dr Litchfield for their help, their encouragement and their time.

I wish to thank Dr Rodriguez-Saona for his help with the interpretation of the data.

I thank my lab mates and office mates for their continuous friendship and support. Without them this journey could have been very uninspiring.

I appreciate Gary Wenneker's and Matt Russell's help with all the numerous tools and equipments.

I want to thank all the companies such as Leprino cheese, Red Arrow USA, PMP fermentation, Tate and Lyle, and Grote Company for providing food products and assistance.

Finally I wish to thank the Food Science Department at The Ohio State University and its employees for their assistance during the completion of my masters.

VITA

December 25, 1974.....Born- Kpalime, Togo

2000.....B.S. Food Science and Technology,
Ohio State University

2000-2004.....Microbiologist- Nestle-USA,
Dublin, OHIO

2004-present.....Graduate Research Associate, The
Ohio State University

FIELDS OF STUDY

Major Field: Food Science and Nutrition

TABLE OF CONTENTS

Abstract	ii
Dedication	iv
Acknowledgements	v
Vita	vi
List of Figures	xi
List of Tables	xiv
Table of Contents	vii
Chapters:	
1 Introduction	1
2 Literature Review	4
2.1 Principle of Electrostatics	4
2.1.1 Electrostatic powder coating	4
2.1.2 Corona charging	6
2.1.3 Transfer efficiency	7
2.1.4 Evenness of electrostatic coating	9
2.2 Powder Properties	10

2.2.1 Particle size and particle size distribution.....	10
2.2.2 Charge to mass ratio.....	11
2.2.3 Powder flowability.....	12
2.3 Triboelectric Charging.....	14
2.4 French Fries	15
2.4.1 French fry manufacture.....	16
2.4.2 French fry color.....	18
2.4.3 Maillard reactions	18
2.4.4 Color measurement	20
2.5. Glucose	22
2.6 Smoke Extract.....	22
2.7 Mozzarella Cheese.....	22
2.7.1 Mozzarella cheese manufacture.....	22
2.7.2 Molds on mozzarella cheese	23
2.8 Antimycotic Agents in Cheese	23
2.8.1 Natamycin	24
2.8.2 Sodium erythorbate.....	24

3	Materials and Methods.....	26
	3.1 Food Powders	26
	3.2 Food Products	26
	3.4 Amount of Powder.....	30
	3.5-Powder Properties.....	30
	3.5.1 Percent transfer efficiency	30
	3.5.2 Particle size	31
	3.5.3 Particle size distribution.....	31
	3.5.4 Powder chargeability	31
	3.5.5 Powder flowability.....	32
	3.6-Color Measurement	33
	3.7-Statistical Analysis	33
	3.8-Evenness	34
4	Results and Discussion	35
	4.1 Transfer Efficiency	35
	4.2 Glucose on French Fries, Smoke on French Fries, Sodium Erythorbate on Cheese.....	37
	4.2.1 Glucose on French fries	37

4.2.2 Smoke extract on French fries	39
4.2.3 Sodium erythorbate on cheese	42
4.3 Evenness	43
4.4 Charge to mass ratio	45
4.4.1 Particle size and charge to mass ratio	46
4.5 Particle Size Distribution, Flowability, Tribocharging.....	49
4.6 Reasons Why Powders May Not Show Improvement: Cellulose with Natamycin on Cheese	51
5 Conclusions.....	54
References.....	55
APPENDIX A: Preliminary and raw data	59
APPENDIX B: Statistical analysis	70

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
3.1	Continuous belt powder coating system.....36
4.1	Transfer efficiency of electrostatic coating is higher than nonelectrostatic coating for all powders except cellulose with natamycin. * Significantly different ($p < 0.05$)..... 36
4.2	Electrostatic coating with glucose produces darker French fries for the same amount of powder as nonelectrostatic coating..... 38
4.3	Electrostatic coating with glucose produces redder French fries for the same amount of powder as nonelectrostatic coating..... 39
4.4	Electrostatic coating with glucose produces redder French fries for the same amount of powder as nonelectrostatic coating..... 39
4.5	Electrostatic coating with smoke extract produces darker French fries for the same amount of powder as nonelectrostatic coating..... 40
4.6	Electrostatic coating with smoke extract produces redder French fries for the same amount of powder as nonelectrostatic coating..... 40
4.7	Electrostatic coating with smoke extract produces redder French fries for the same amount of powder as nonelectrostatic coating..... 41

4.8	The shelf life of cheese coated with sodium erythorbate is significantly longer when electrostatic was used instead of nonelectrostatic coating. p <0.05.	42
4.9	Electrostatically coated French fries had a more even color than nonelectrostatically coated French fries.....	44
4.10	Glucose and smoke extract is more even in color when coated electrostatically than nonelectrostatically.* significantly different (p<0.05).....	45
4.11	Charge to mass ratio of sodium erythorbate, glucose, and smoke extract is significantly greater with electrostatic coating while there is no difference for cellulose with natamycin.* Significantly different. (p<0.05).....	46
4.12	Charge to mass ratio of powder increases with decreasing particle size of glucose.	47
4.13	Redness decreases with increasing particle size for both electrostatic and nonelectrostatic coating of 20mg of glucose on French fries.	47
4.14	Redness decreases with increasing particle size for both electrostatic and nonelectrostatic coating of 20mg of glucose on French fries.	48
4.15	The shelf life of cheese coated with cellulose with natamycin was not different when electrostatic or nonelectrostatic coating was used.....	51
A.1	Browning index of glucose applied onto French fries.....	60
A.2	Delta E of glucose applied onto French fries.....	61
A.3	b value of glucose applied onto French fries	61
A.4	Chroma of glucose applied onto French fries.....	62

A.5	Browning index of smoke extract applied onto French fries.....	62
A.6	Delta E of smoke extract applied onto French fries.....	63
A.7	b value of smoke extract applied onto French fries	63
A.8	Chroma of smoke extract applied onto French fries.....	64
A.9	%RSD of a value showing significant difference between electrostatic and nonelectrostatic coating. * Significantly different ($p<0.05$).	64
A.10	%RSD of L value showing significant difference between electrostatic and nonelectrostatic coating. * Significantly different ($p<0.05$)	65
A.11	%RSD of Delta E showing significant difference between electrostatic and nonelectrostatic coating. * Significantly different ($p<0.05$)	65
A.12	%RSD of Browning index showing significant difference between electrostatic and nonelectrostatic coating. * Significantly different ($p<0.05$).....	66

LIST OF TABLES

<u>Table</u>	<u>Page</u>
2.1	Flow characteristics of powders using angle of repose (Adapted from de Jong and others, 1999) 14
3.1	Flow characteristics of powders using angle of repose (Adapted from de Jong and others, 1999) 33
4.1	Particle size distribution, angle of repose and flowability description of glucose, smoke extract, sodium erythorbate, and cellulose with natamycin. 50
A.1	Transfer efficiency (%) of all powders with electrostatic coating and nonelectrostatic coating. 60
A.2	Flowability of powders 67
A.3	Particle size of all powders 67
A.4	Charge to mass ratio ($\mu\text{C/Kg}$) of glucose, smoke extract, sodium erythorbate, and cellulose with natamycin..... 68

A.5	Experimental conditions. Belt width was 30cm and sample area for French fries was 6.4516cm ² and was 22.5 cm ² for cheese	69
B.1	Regression analysis of color variables vs amount, method, and interaction for electrostatically coated French fries vs nonelectrostatically coated French fries	71
B.2	Regression analysis of color variables vs amount, method, and interaction for electrostatically coated French fries vs nonelectrostatically coated French fries	71
B.3	Regression analysis of shelf life in days vs amount, method, and interaction for electrostatically coated cheese vs nonelectrostatically coated French fries.	72

CHAPTER 1

INTRODUCTION

Electrostatic coating is widely used in the painting industry and the snack food industry as an alternative to traditional powder coating. It has been shown to produce more uniform coating and decreased dust in the production line thus decreasing the risk of explosion and health complications for humans (Moore 1968). In addition it has been shown to improve transfer efficiency (Biehl and Barringer 2003). During electrostatic coating, electrical forces are created by the interaction between the charged powder and the electrical field. In corona charging, a fine gauge wire is connected to a high voltage generator of either positive or negative polarity resulting in the ionization of air, the subsequent separation of charge and the creation of unipolar molecules (Hughes 1997). Charged particles are then conveyed to the ground creating an evenly distributed cloud over the substrate.

Electrostatic coating can overcome the problem of uneven distribution of powder on the surface of the substrate usually found in traditional coating methods. Charged particles are created in the coating zone and can achieve more homogenous coating even

on difficult shapes, enhancing the quality of the finished product without the overuse of expensive powders (Clark 1995). Electrostatic coating promotes an even dispersion of the powder over all the surfaces of the products (Anon 1996). Sensory and instrumental methods have found the uniformity of electrostatically coated chips to be more even and yellowness to have a smaller standard deviation than nonelectrostatically coated chips (Ratanatriwong and others 2003). In addition, electrostatic salter lines had a lower average coefficient of variability of salt than conventional salters during coating of crackers (Strietelmeier and Reynolds 1969).

Charge to mass ratio is an important indicator of the efficiency of electrostatic coating. Improvement in coating efficiency during electrostatic coating is dependant on a large charge to mass ratio. The larger the charge during electrostatic coating, the greater the improvement seen with the process (Mazumder and others 1997). Charging of the powder is dependant on the size of the particle. Smaller particles have more surface area so they can charge more during electrostatic coating (Bailey 1998).

The main attributes of French fries are color, which should be golden, texture, and total appearance which are usually dependent on the chemical components of the potato (Lisinska and Leszczynsk 1989). Sometimes based on the storage and usage, it becomes necessary to infuse potatoes with a reducing sugar-based solution in order to maintain appealing color in the resulting French fries. The amount of color on French fries is proportional to the amount of reducing sugars or carbonyl compounds of the potatoes (Marquez and Anon 1986). Smoke extract is a good source of carbonyls and glucose is a reducing sugar.

Antimycotic agents have been used in cheese and cheese products to extend their shelf life. Natamycin, also known as Pimaricin, is an antimycotic agent and a food additive used to protect cheese from mold and yeast growth. Natamycin is currently approved by the FDA for use on the surface of cuts and slices of cheese where the standards for such cheese provides for the use of safe and suitable mold inhibiting ingredients. Natamycin may be applied to cheese by dipping or by spraying a liquid solution that contains 200 to 300 parts per million (ppm) of the additive. A smaller amount of Natamycin compared to sorbates and propionates, is usually needed to achieve a better preservation of the cheese (Jay 1998) without any flavor or natural microflora changes (de Ruig and van den Berg 1985). Sodium erythorbate is an antioxidant that is used as an oxygen scavenger, chelating agent, and reducing agent. It can be used to extend the shelf life as well as improve the safety of some foods. It is occasionally used in conjunction with other preservatives in dairy products.

It is hypothesized that electrostatic coating will improve the transfer efficiency of browning agents on French fries and antimycotic agents on cheese. In addition, it has been theorized that electrostatic coating will improve the functionality of these food powders when the same amount of powder is used to coat several food items.

CHAPTER 2

LITERATURE REVIEW

2.1 Principle of Electrostatics:

Electrostatic behavior of substances has been known for many years. This process was first reported more than 2500 years ago, when amber that had been rubbed on silk picked up small particles (Cross 1987). However the process received more attention only in the 20th century when the reason for charge separation was tentatively explained (Cross 1987). Electrostatic forces are created through the charging of two materials, where the electrical charges created at the surface distribute themselves in such a way that an electrical potential exists at the interface. Particles can be charged when they are either stationary or moving using electrostatics (Hendricks 1973). Small particles are capable of carrying significant charges and they are susceptible to Columbic forces when exposed to electric field (Hughes 1997).

Due to its advantages, electrostatics is being applied to many areas including painting, pesticide spraying, and copy machine technology in the food industry (Hughes 1997). Electrostatics in the painting industry involves powder coating where the ability to control charged particles is crucial in maintaining an improved deposition on the surface of a material.

2.1.1 Electrostatic powder coating:

Powder coating is used to improve the flavor and the appearance of food products. Applying powders on foods products can results in unevenly coated products resulting in poor flavor distribution (Clark 1995). In the attempt to alleviate these problems, the industry tried to dilute the seasoning in bulking agents in order to over-apply powders onto the products (Seighman 2001). The method was not very profitable because excess powder tends to fall off even though a more even coating was achieved. In addition, traditional powder coating has been found to create dust especially when powder size is small because they tend to stay suspended in the air (Anon 1992). Dust can be responsible for explosions and respiratory distress in humans. Severe overuse of powders and contamination of conveyors and equipments are also problems associated with traditional methods of coating (Anon 1996). In order to assuage the problems listed above, electrostatic powder coating was evaluated as an alternative to traditional powder coating.

The basic concept behind electrostatic coating is the attraction between the negatively charged powder and the nearest grounded object. The charged particles repel each other, forming a cloud as they approach the substrate creating a powder cloud across the food. Electrostatic powder coating involves the application of electrical charge to food powders where charged particles repel each other to create an even coating on the food products. Coating is created by the fact that the charged powder tends to seek the nearest ground because of Coulombs law resulting in increased transfer efficiency and reduced dust (Hughes 1997). Because of the ability of the powders to search for the

nearest ground, dust creation and powder waste are considerably minimized. Adhesion and transfer efficiency are also improved by electrostatic coating. Electrostatic is preferable to traditional coating because of its ability to give higher transfer efficiency, more even coating, decreased powder usage and decreased dust (Bailey 1998).

The most important phenomena seen in electrostatic powder coating is the wraparound effect. Powder particles charge in the electrical field, creating a uniform cloud due to repulsion between particles. Charged particles are directed toward the nearest ground forming a uniform coating not only on the surface but also in the concealed areas due to the wraparound effect (Bailey 1998).

A major disadvantage associated with electrostatic powder coating is back ionization. Charged particles are conveyed onto the substrate via aerodynamical forces due to the air flow of the machine. The attraction of the charged powder to the substrate is due to the mirror charges created on the substrate and will remain as long as powder deposited during the process remains on the substrate. Back ionization is created when powder build up on the substrate generates a charge breakdown between the surface of the coated powder and the substrate. This will cause the charge to migrate away from the substrate toward the powder applicator leading to neutralization or reverse charging. This process will lead to a decrease in powder deposition due to self limitation of the coating thickness (Hughes 1984).

2.1.2 Corona charging:

There are three types of electrostatic charging methods used in the industry: Corona, triboelectric and induced charging. Corona charging is the preferred method within the industry (Anon 1996).

In corona, a sharp pointed needle-like electrode or a fine gauge wire is used. During corona charging an electrical field is created by the application of a high voltage source. Negative high voltage is the most common but a positive high voltage has also been used in a few applications (Bailey 1998). The process results in ionization of the air generating free ions and electrons creating unipolarly charged powders (Hughes 1984). A corona zone is created when a high voltage potential is applied from the needle point or the fine gauge wire. High velocity electrons are emitted and are accelerated by the electrostatic field in the region of the electrode due to Coulombic forces (Bailey 1998). The powder particle moving through the corona zone will pick up the appropriate charge and will be directed to the grounded object via electrostatic, gravitational, and aerodynamical forces. Aerodynamic forces are directed by the flow of air and gravitational forces involve the attraction of the particle downward especially large particles. The maximum charge a particle can acquire is express by the Panthenier equation:

$q = 4\pi\epsilon_0 a^2 E \rho$, where q is the maximum charge, ϵ_0 is the permittivity of free space, a is the radius of the particle, E the electrical field and ρ is a constant associated with the dielectric constant (Hughes 1997).

2.1.3 Transfer efficiency:

Transfer efficiency could be defined as the ratio of the mass of powder deposited on the object to the mass of the powder fed through the coating system (Sampuran-singh and Bright 1978). A transfer efficiency of 80% could be obtained with a low flow rate and high voltage during electrostatic coating (Sampuran-singh and Bright 1978). Transfer efficiency depends on both aerodynamic and electrostatic forces experienced by the powder during deposition (Mazumder and others 1997). Transfer efficiency of natamycin increases with electrostatic coating with the tumble drum method (Elayedath and Barringer 2002).

Ratanatriwong and others (2003) found that transfer efficiency of the seasoning powders coated electrostatically was twice those coated nonelectrostatically with smaller nacho powders being the best and large salt and vinegar showing the least improvement. It was found that for both electrostatic and nonelectrostatic coating transfer efficiency increased as particle size decreased (Biehl and Barringer 2003). Transfer efficiency for electrostatic coating was correlated with increased flowability and chargeability but not with size. Free flowing and highly charged powders showed increased transfer efficiency with electrostatic coating regardless of size (Biehl and Barringer 2003).

Ricks and others (2002) found that transfer efficiency increased as particle size and flowability increased for nonelectrostatic coating. Transfer efficiency is not however affected by improvement in the overall charge of the powder. It was also found that transfer efficiency of electrostatic coating improved over nonelectrostatic coating for

68% of the powders and was affected by size, flow index and particle density. Smaller particles, decreased flow index, and increased particle density showed greater improvement during electrostatic coating (Ricks and others 2002).

Miller and Barringer (2002) found that the smaller the particle size of salt (sodium chloride), the greater the improvement with electrostatic coating for hollow pyramids salts. Salt shape was also significant as cube salt had the highest transfer efficiency, followed by crushed flake, hollow pyramids and porous cube.

Biehl and Barringer (2004) found smaller particle size produced greater transfer efficiency in a gravity tumble drum system which is opposite to what was found using a conveyor coating system where larger particle sizes provided greater transfer efficiency during nonelectrostatic coating. Free flowing powders and greater chargeability provided the highest transfer efficiency.

Mazumder and others (1997) found that transfer efficiency is dependant on the particle size distribution of a powder and is best when the distribution is narrow. The greater efficiency in electrostatic coating is due to the charge of the particles when they pass through the corona zone.

2.1.4 Evenness of electrostatic coating:

One of the major problems with powder coating is powder waste. After coating, products often experience fall off of flavor resulting in a poor distribution of powder which usually affects the product negatively. In order to minimize the problem, manufacturers usually overuse flavor, hopeful that enough is leftover on the product after

roll off, to still provide good flavor intensity once it reaches the consumer. Products such as salty fried snacks have been facing this problem (Clark 1995). Electrostatic coating helps achieve more homogeneous coating even on difficult shapes with considerable less flavor waste (Anon 1996). This is possible because the strong attraction of highly charged flavor particles and the substrate combined with a dispersal system makes it possible to apply an even coating thus creating good flavor notes on products (Anon 1996). Electrostatics was also found in the painting industry as capable of giving more consistency and even coating (Pannell 1980). In addition, Ratanatriwong and others (2003) found that electrostatically coated chips with seasonings had smaller standard deviations of yellowness thus were more evenly coated than nonelectrostatically coated samples. They also found through sensory evaluation methods that electrostatically coated chips were more uniform in appearance of coating. Electrostatic coating can maintain uniform spacing of particles during coating by inducing a negative charge on their surface causing the particles to repel each other (Strietelmeier and Reynolds 1969). The same authors also found that the average variation of electrostatic coating of salt onto crackers was much lower than in the conventional method.

2.2 Powder Properties:

2.2.1 Particle size and particle size distribution:

The size of a particle is a major determinant of its performance in powder coating for both nonelectrostatic and electrostatic coating (Horinka 1995). It is also the most important factor for determining the behavior of the powder. In a coating system, the

deposition of large particles is guided by gravitational forces while smaller particles are directed by additional forces such as Columbic and electrostatic forces. Size can regulate various physical phenomena such as flowability, solubility and more. Powders are made into specific sizes depending on their application. Optimum particle size for electrostatics is in the range of 30-40 μ m (Bailey 1998). Smaller particles were more effective in the tumble drum while size was non significant for conveyor belt coating (Biehl and Barringer 2004). For pyramid salt, smaller particles showed the greatest improvement with electrostatic coating while size was not significant for crushed flake salts (Miller and Barringer 2002). Similar findings was also published by Ricks and others (2002) who found that smaller particles generated greater coating improvement than larger particles, up to 200%.

Particle size distribution only determines the properties of individual particles inside a mixture. Particle size distribution can be divided into four categories: skewed right or left, mixed and symmetric. Small variations in surface properties can results in greater difference in the property of the bulk powder thus size distribution is as important as size alone (Peleg 1987). The transfer efficiency of a coating process and the quality depends on the particle aerodynamic diameter therefore the quality of the process depends critically on the uniformity of the size distribution: a narrow size distribution is desired. A narrow size distribution is important to maintain a consistent performance of the coating system (Mazumder and others 1997).

2.2.2 Charge to mass ratio:

Charge to mass ratio of the powder is defined as the measure of the performance of an electrostatic system (Hughes 1984). In order to achieve a uniform deposition particles need to be efficiently charged. Smaller particles have a greater surface area so they are able to obtain a larger charge to mass ratio than larger particles during electrostatic coating. Consequently, smaller particle can charge more efficiently than larger particles (Bailey 1998). Charging is inversely proportional to the radius of the particle, so as they become larger they tend to charge less efficiently (Horinka 1995).

Ratanatriwong (2003) found charge to mass ratio positively correlated to improvement of the coating efficiency. This is similar to what was published by Miller and Barringer (2002) who found smaller salts having larger charge to mass ratio had a greater coating efficiency with electrostatics. Powders that showed the greatest charge improvement resulted in the greatest coating improvement with electrostatic coating (Biehl and Barringer 2003). However, Ricks and others (2002) did not find chargeability to impact the improvement seen with coating efficiency of salts. This finding was probably due to sensitivity of the apparatus used in the measurements.

2.2.3 Powder flowability:

Powder flowability depends on external conditions such as temperature and compression. Free flowing powders can develop flow problems after an extended period of storage (Teunou and Fitzpatrick 2000). Powders may become more compact when

submitted to compression stress resulting in more regions of contacts thus generating more cohesive powders (Malby and others 1993). This state of cohesiveness may increase over time. Some powders may require the addition of free flow agents to aid the flowing property of a powder, which does not usually affect the physical properties of the powder. It is usually assumed that powders with size larger than 200 μ m are free flowing while other sizes are subjected to cohesion because flowability is more difficult (Tenou and others 1999). Often various types of flow conditioners such as silicates, stearates, phosphate, and starch are used in the food industry (Peleg 1977). In addition to being used as a solid barrier between particles, or as lubricants of the solid surface, flow agents can also be used to neutralize electrostatic charge (Peleg 1977). Flowability is a very important property during coating because a uniform mass flow rate must be maintained to obtain a uniform coating (Mazumder and others 1997).

The more free-flowing is the powder, the greater is the coating improvement for electrostatic coating using both Hausner ratio and angle of repose (Biehl and Barringer 2003). The finding was also true for nonelectrostatic coating. This is opposite to what was published by Ricks and others (2002) who found that free flowing powders with increased flow index decreased coating efficiency for electrostatic coating. Large coating improvement occurred for powders that are not free flowing. Hausner ratio and angle of repose were not statistically significant because they rely on other flow characteristics. The results were similar during nonelectrostatic coating where coating improvement increased as powder became more free-flowing (Ricks and others 2002).

Flow Characteristics	Angle of Repose(°)
Non flowing-cohesive	>60
Fairly free-flowing	45-60
Free-flowing	30-45
Excellent flowing	10-30
Aerated	<10

Table 2. 1: Flow characteristics of powders using angle of repose (Adapted from de Jong and others, 1999)

2.3 Triboelectric Charging:

Tribocharging involves the friction due to contact between two like materials. During the rubbing of the materials there is a charge transfer that will affect the polarity of the materials. Most frictionally charged surfaces have both positively and negatively charged areas but one polarity predominates, determining the overall charge of the surface (Cross 1987). This phenomenon during tribocharging has been explained by the change of energy in the system, resulting in materials that are charged with opposite charges. Tribocharging can also happen when powders are transported via pipes or other materials. Particles are subjected to collisions with the wall of the pipe and exchange charge (Bailey 1998). The charge exchange may be expressed as follows:

$$q = \frac{q_c}{K} (1 - e^{-kn}) + q_p e^{-kn}$$

$K = k + l$ (k is the charge reduction factor due to particle charge and space-charge field, and l is the charge loss due to conduction during contact), n is the number of collisions, q_c is the charge to contact potential, q total charge on the particle and q_p is the pre-impact charge of the particle. Based on the pre-impact charge a particle may either gain or lose charge upon successive impacts until final saturation charge is attained (Bailey 1998).

It was also found by Murtomaa and Laine (2000) that powder-powder contacts between two different compounds may generate frictional charge where one can positively charge and the other negatively charge. Additional friction can also happen when a third material is present. Neutralization of these charges may occur during coating depending on the polarity of the charge being used.

Hughes (1997) described tribocharging as the process of two materials coming into intimate contact and resulting in an imbalance of charge between the two materials. Based on the structure of the materials, rearrangement of charges may occur in trying to achieve electrical balance. Migration of charges will occur; the degree and the direction will depend on the tribocharging of the particles.

Powder flow through an orifice depends on the size of the orifice and the particle. Large particles have the tendency to obstruct the orifice thus decreasing flow rate. The tendency of powders to cause blockage is dependant on the mechanical properties of the material and its ability to accumulate static charge. Therefore the control of these properties is important in the control of powder flow during coating (Howell 2000).

When the polarity of the corona is the same as the polarity of the charge created by tribocharging, a higher coating efficiency is obtained. Higher tribocharging effect was

found to produce lower coating efficiency and cohesiveness was also found to create higher tribocharging effects on the powder (Sumawi and Barringer 2005).

2.4 French Fries:

More than 30% of the annual potato crop produced in the is used in the processing of French fries and similar products (Lucier and others 1991). They are found on the menu of most fast-foods restaurants and are the best selling item in both commercial and non-commercial foodservice companies. Furthermore, the French fry business is considered to be one of the most profitable items in food service. In 1992, frozen potato products, which include French fries, were the #1 prepared style of potatoes in the U.S., with a 32 % market share. In that same year, French fries were featured in more than 300 television commercials in the U.S (Davis 2005). There are two main types of French fries manufactured in the U.S: Partially fried French fries and chilled French fries (Lisinska and Leszczynsk 1989).

2.4.1 French fry manufacture:

Potatoes are usually transported to the plants from the field via railroad cars or trucks. They are sorted in order to remove stones, pebbles, and other unwanted materials. The potatoes get graded by size, usually after being washed in drum washers. They eventually get weighed before being steam or lye peeled and immersed in water to avoid

enzymatic browning. Cutting of the potatoes is usually done using a hydro-cutting machine. The tubers are cut along their longer axis in order to obtain long French Fries. The potatoes still immersed in water are then transported through pipes in lengthwise position to the blancher. Potatoes strip that are too thin, too short or broken are removed prior to blanching. Blanching is done on the potato strips to improve the quality of the finished product, reduce the absorption of fat due to starch gelatinization, reduce frying time, inactivate enzymes and improve the texture of the finished product. There are various blanching methods but the most common are steam and water blanching. Time and temperature of the blanching process is dependant on the size and the quality of the raw material. On the average a temperature of 60-85°C is desirable during the process. To prevent discoloration and maintain texture and color, sodium pyrophosphate, magnesium salts, calcium salts, dilute sugar solution or starch solution may be added to the blanching water or steam. The additives are used to assure a uniform golden color with nice texture of the finished products. Excess moisture is then removed from the potato strips by using dewatering screens and warm air, to control cooking time and fat intake (Lisinska and Leszczynsk 1989). Occasionally, continuous conveyor driers are also used to remove excess moisture.

In par-fried potato frying the dried potatoes are fed into the fryer using a vibratory divider. The oil is heated at a temperature of 170°C if hydrogenated or to 180°C otherwise and needs to be changed every 16-22 hrs to avoid foaming, increased viscosity and density that may lead to higher off-flavors and odors in the finished products. Par-frying is usually done to inactivate the reminder of the enzymes left after blanching and

to maintain the color and the texture over time. French fries are drained immediately to avoid more fat intake using a belt type or vibrating defatters. French fries are air-cooled for about 20 min to improve the texture and the efficiency of the freezing process. Sometimes an inspection step may occur where dark colored or other defective French fries are removed. French fries are then salted and frozen using either a belt freezer or a fluidized tunnel depending on whether loose or packed finished products are desired. Freezing time may vary but is usually around -20°C for 7-12 min. Products are packed in the desired packages, where high quality frozen and stability during transportation are maintained (Lisinska and Leszczynsk 1989).

2.4.2 French fry color:

The main attributes for French fries are color and texture (Nourian and others 2003). Color however, is the most important attribute that will determine consumer intent to purchase the product since it is seen as a predictor of flavor and taste (Nourian and others 2003). Color is expected to be a light golden color without any brown or black spots (Lisinska and Leszczynsk 1989). The color of French fries is mainly dependant on the chemical composition of the raw materials (Smith 1987). The amount of reducing sugar is very important and should be around 0.5% to obtain the appropriate color (Lisinska and Leszczynsk 1989). Blanching is one of the processes that is designed to improve the color of the finished product with the addition of salts, sulfites and sugar and starch solutions. The formation of color in French fries is closely related to the reaction rate of Maillard browning. Color of French fries is closely related to the amount of

reducing sugars in the potato tuber. Eliminating reducing sugars and amino acids from potatoes, had an effect on the color resulting in lower chroma, higher hue angle and increased yellowness of chips (Rodriguez-Saona and others 1997). Reducing sugars have the most influence on the lightness of the potato chip color. Reducing sugar content showed a linear relationship with lightness and hue angle and a quadratic relationship with chroma (Rodriguez-Saona and others 1997).

2.4.3 Maillard reactions:

French fry color is dependant on a series of reactions referred to as Maillard reactions. Maillard reaction is a type of non-enzymatic browning between reducing sugars or carbonyl compounds and free amino groups, which combine with the time and temperature of heat (Marquez and Anon 1986). It is also dependant on other factors such as moisture content, water activity and pH. The Maillard reaction is optimum above 100°C and is limited by the amount of reducing sugar or carbonyl present (Rodriguez-Saona and others 1997). In most foods amino acids are seldom the limiting factor of Maillard reaction. Browning in potato is highly correlated to the amount of principal reducing sugars such as glucose and fructose (Gray and Hughes 1978). During French fry manufacture, browning of the product is obtained during the heating of the oil where the high temperature causes reducing sugars and/or carbonyl compounds to react with the free amino group (Marquez and Anon 1986), to form brown compounds. The Maillard reaction is a complex reaction series during which brown melanoidins pigments are formed. Firstly there is a condensation of the carbonyl group of a reducing sugar such as

an aldose and the free amino group usually found on protein or amino acids to form a glycosylamine. This product, being very unstable will undergo the “Amadori rearrangement” where ketosamines are formed. Ketosamines may experience subsequent dehydration to form dehydro reductones, very powerful antioxidants and caramel-like products. Smaller chains of diacetyl and acetol may form and go through Strecker degradation with amino acids to form aldehydes with one less carbon atom together with carbon dioxide or in the absence of amino acids to give nitrogen-free polymers. A final path for Maillard reactions involves loss of water molecules and a reaction of amino acids (Schiff/base furfural path) leading to formation of brown polymers called melanoidins. Melanoidins pigments have an effect on the color, flavor and texture of the food products.

2.4.4 Color measurement:

Color is often the first sensory quality by which foods are judged and could also indicate chemical changes and reactions that occur in the food items (Zamora and Hindalgo 2005). In addition to natural pigments that may often occur in food products, color may also be modified by a series of reactions causing food browning (Friedman 1996). Sometimes it may become necessary to quantify the amount of color contained in foods in order to correlate it to consumer interest. There are a number of pieces of equipment and devices designed for the sole purpose of measurement of color other than visual inspections.

First of all, there is a method that is designed to mimic the visual perception of color. It is called the tristimulus colorimeter where the ρ , γ and β cones of the eye are replaced with red, green and blue filters or the RGB or XYZ color scale (Hutchings 1999). Another method for color measurement involves the spectral curve. Spectrophotometry is used to measure close to the real color of the foods similar to the previous methods using a different color scale. Finally, the last method used is classified as the monochromatic colorimeter. The values obtained with this instrumentation are not the true color but the angle of reflectance of light on the food products (Good 2004). There are various color scales associated with the three methods of color measurements. The most widely used color scale was instituted by the Commission Internationale de L'eclairage (CIE) and is known as the L^*a^*b scale. These three-dimensional scales are supported by the theory that the red, green and blue human eye cone receptor signals are re-mixed into black-white, red-green, and yellow-blue opponent colors as the signals move from the eye to the brain (Good 2004). In the $L^*a^*b^*$ color scale L is defined as lightness where the axis from 0 black to 100 white. The a value is defined as redness where positive values are red and negative values are green.

Other color measurements can be derived from this color space such as delta E, Browning index, hue angle and chroma. Delta E is the size of the total color difference, but does not give information about how the colors differ. The larger the ΔE value, the larger the color difference. ΔE can be calculated using the following equation: $\Delta E = ((L - L')^2 + (a - a')^2 + (b - b')^2)^{1/2}$ where L' , a' , b' are the initial color measurement and L , a , b the color measured after a change was made to the food product. Browning index is a

variable used to estimate the amount of browning in a product. It can be quantify using the equation $BI = (100(x-0.31))/0.172$ and $x = (a + 1.75L) / (5.645L + a - 3.012b)$ where L, a, b are three measured color variables from the product.

Hue angle is the angle between chroma and a value. 0°C is red, 90 °C is yellow, green is 180 °C, and blue is 270 °C. Hue angle can be calculated using the following equation: Hue angle $\theta = \text{ARCTAN}(b/a)$.

Chroma is the attribute of visual perception of the saturated area with a particular color or hue. It is mostly defined as the saturation or purity level of the hue angle and can be calculated using the following equation:

$$(a^2 + b^2)^{1/2}.$$

2.5. Glucose:

Glucose ($C_6H_{12}O_6$) is a commercial sweetener made from the hydrolysis of starch by the action of heat and enzymes. It is a reducing sugar that produces browning at high temperatures in various foods including potato products (Igoe and Hui 1999).

2.6 Smoke Extract:

Smoke extract powders are mostly used in the meat industry to impart flavor and color. They are composed of acids, phenols and carbonyl compounds (Husaini and Cooper 1957). Carbonyl compounds found in the smoke extract are a major contributor to browning when they react with the amino groups found in various food products (Chen

and Issenberg 1972). Carbonyl compounds are the result of wood pyrolysis used to generate the smoke extract.

2.7 Mozzarella Cheese:

Cheese is one the most consumed dairy products around the world especially in the United States. Close to half of the milk produced by U.S. dairy farmers is now utilized in cheese production (Vitaliano 2000).

2.7.1 Mozzarella cheese manufacture:

Mozzarella cheese is manufactured with standard pasteurized milk that is cultured, coagulated, cut, and cooked. The curd is then drained to remove the whey, and stirred until acidity develops. Mozzarella cheese is made with a miller curd process where the speed at which the curd is pilled determines the amount of moisture present in the final product (Law 1999). The obtained curd is then subjected to kneading and plasticizing in hot water, and then molded to the desired shape before being salted in chilled brine. Salt brining is crucial to inactivate milk coagulant, to reduce starter culture activity and decrease the potential of proteolysis while imparting the fibrous structure found in mozzarella cheese.

2.7.2 Molds on mozzarella cheese:

One of the most important spoilage problems in the cheese industry is due to molds. Spoilage due to mold causes the product to have surface discoloration and off flavor (Kulkarni and others 1968). Cheese spoilage resulting from mold growth is enhanced where more surface area is exposed. (Hocking 1997). *Penicillium* species are the most prominent and widespread molds found in cheese. *P. commune* is the most frequently found mold on cheese (Lund and others 1995). In addition, *P. roqueforti* has also been identified as a spoilage mold even though it is commonly used in the production of Roquefort cheese. Other uncommon mold species are *Cladosporium* found on wet cheese surfaces and phoma-type molds (Law 1999). Most spoilage molds found in cheese can grow at refrigerated temperatures, sometimes close to freezing temperatures, at low water activity, in a variable pH range and can withstand high salt content.

2.8 Antimycotic Agents in Cheese:

There are various types of antimycoting agents approved for preserving cheese; most common ones are sorbates, propionates, and natamycin (Suloff and others 2003). Even though sorbates are effective in delaying mold growth in cheese, they are often degraded through decarboxylation (Finol and others 1982) and can form volatile compounds that are associated with off flavor in cheese (Eiroa and others 1999). Therefore the preferred antimycotic agent used in cheese is natamycin.

2.8.1 Natamycin:

Natamycin, also known as Pimaricin, tennecetin and miprozine, is commonly used to protect cheese from mold and yeast growth (Jay 1998). It is a propylene that acts by binding the membrane sterols, distorting the selectivity of the membrane permeability (Jay 1998). It is currently approved by the FDA to be used on cheese by dipping or spraying a solution that contains 200-300 parts per million of the additive. In native form, natamycin exist as an insoluble crystal and is extremely insoluble in water (0.050-0.100mg/ml). Only about 5-10ppm of the prepared solution of natamycin will actually enter the cheese. The ability of natamycin to prevent or retard surface mold growth in cheese is dependant on its distribution on the surface of the food products. However due to its insoluble nature its application to block cheese is often expensive and requires a large excess of natamycin.

2.8.2 Sodium erythorbate:

Sodium erythorbate is the sodium salt of erythorbic acid. It is also called erythorbic acid sodium salt (Lanigan 1999). Sodium erythorbate is a common antioxidant due to its ene-diol structure (Anon 1995). The reactivity of this ene-diol allows sodium erythorbate to serve as an oxygen scavenger, chelating agent and reducing agent. It can be found in crystalline form but is only active when in solution. Solubility is greater than 100mg/ml of water. pH of a solution of sodium erythorbate is between 5.5-8.0 (Lanigan 1999). It is used as a antioxidant in milk and other products such as meat and cured meat products by speeding up color development, in seafood by delaying oxidation, and in

CHAPTER 3

MATERIALS AND METHODS

3.1 Food Powders:

Food powders used were smoke extract (VSA, Red Arrow Inc, Manitowoc, WI), food grade glucose (Meritose 200, Tate & Lyle, Decatur, IL), sodium erythorbate (Eribate, PMP Fermentation, Peoria, IL) and cellulose with natamycin (Solkafloc EXT, International Fiber Corporation, Urbana, OH). Smaller sizes of glucose were obtained using an ultra centrifuge mill (ZM 100, Retsch GmbH, Rheinische, Germany).

3.2 Food Products:

Par-fried French fries (Lamb Weston Inland Valley French fries, regular cut, Eagle, ID) were fried with a Rival 3.0 gallon deep fryer (Rival products, El Paso, TX) for 2 min for powder smoke extract and 3 min for glucose at an initial temperature of 182°C, intermediary temperatures of 160 °C and final temperature of 175 °C using soybean oil (GFS vegetable oil, Grand Rapids, MI). Frying oil was changed after each batch.

Part-skim mozzarella cheese was sliced in pieces using a multi slicer (613 –VS multi slicer, JE Grote Company, Columbus, OH). Cheese slices measured 4.5x 5cm and 0.5-0.7 mm in thickness.

3.3 Food Coating:

Figure 3. 1: Continuous Belt Powder Coating System.

An electrostatic applicator powder system (fig 3.1), (Terronics Development Corp., Elwood, IN) was used to apply the powders at 0 kV for nonelectrostatic and -25 kV for negative corona electrostatic coating. One bag of French fries was defrosted overnight at refrigerated temperature. 15 French fries were adjusted to measure 5.08 x 1.27x 1cm each, placed on 20x25 cm trays, were located on top of a continuous, grounded conveyor belt. The French fries were numbered from 1 to 15 using a Fisherbrand marking pen (Fisher, Hampton, NH), wiping the tip of the marker between each marking. They were placed on a moving foil conveyor belt and surface coated with

either glucose or smoke extract once they reached the powder zone. Belt speeds and flow rates were measured during all experiments and adjusted in order to obtain overlaps between electrostatic and nonelectrostatic data. Belt speeds were between 20-95 cm/min while powder rates were 0.80- 50 g/min. Variability of flow rate and belt speed is due to the nature of the powders used during these experiments (Table A.5).

The products are coated through a continuous movement of the conveyor belt. Compressor air (5.0 hp, 15.0 gallon tank, Model WL650800AJ, Campell Hausfield, OH) was connected to the system for air supply. The airflow setting for the experiment was 30 psi for direct left, 7 psi for direct right, 17 psi for mid inject, 30 psi for the back inject with a velocity of 4.07 m/s. Food powders were continuously fed through the machine using a volumetric feeder with a flexible hopper (Schenck AccuRate Whitewater, WI). Powder rate and belt speed were crucial in maintaining reproducibility throughout the experiment and were measured daily.

A refrigerated air dryer (Refrigerated air dryer, model IDF1E, SMC Corporation, Tokyo, Japan), was used to assure dryness of the air entering the system. A hygrometer (Fisherbrand Digital Relative Humidity/Temperature Meter, Hampton, NH) was used to record the relative humidity daily. A relative humidity of 32-35% was maintained during these experiments. If the relative humidity was lower than 32%, a humidifier (Honeywell 4.0 Gal. White/Blue Tank Cool Mist Humidifier, Morristown, NJ) was used to adjust it accordingly. If the humidity was above 35%, dehumidification was achieved using a dehumidifier (Maytag 45 pint dehumidifier model M7DH45B2AA, O'Fallon, MO).

French fries were weighed before and after being coated, then fried. The French fry samples were then left to cool at room temperature for 30-45 min before color measurements were taken. An uncoated control was prepared. Powders used in these experiments were stored in tightly sealed containers or bags at 35% humidity or lower. Containers were only opened during coating and resealed for the next experiment.

Twelve cheese slices measuring 4.5 x 5 and 0.5- 0.7 mm in thickness were placed on trays (20x25cm). Two trays or 24 samples were coated via the continuous coating system. Cheese pieces were coated with either sodium erythorbate or cellulose with natamycin. The airflow setting for the experiment was 30 psi for direct left, 15 psi for direct right, 20 psi for mid inject, 30 psi for the back inject, with a velocity of 5m/s. 12 samples were stored in each 2.5 gallon Ziploc Hefty one zip bag (36.5cm x 40.6cm), (Pactiv Corporation, Lake Forest, IL) at 3-5°C for 2 months or until appearance of one mold colony of at least 0.5 cm in diameter on the surface of the samples. An uncoated control was prepared. Experiments were performed in duplicate.

3.4 Amount of Powder:

In order to account for weight loss during coating, samples were run through the coating system but not coated, and weight loss was recorded. Amount of powder was calculated by adding the amount of weight loss (moisture loss) to the amount of weight gained during powder coating.

Amount of powder was calculated using the equation:

$$\text{Amount of powder (mg)} = ((\text{Initial weight (g)} - \text{intermediate weight (g)}) + (\text{final weight (g)} - \text{Intermediate weight (g)}) * 100)$$

3.5-Powder Properties:

3.5.1 Percent transfer efficiency:

Once the amount of powder was determined, the percent transfer efficiency was calculated using the following equation:

$$\% \text{Transfer efficiency} = \frac{\text{Powder on sample (g)}}{\frac{(\text{Flow rate g/min})(\text{Sample area cm}^2)}{(\text{Belt speed cm/min})(\text{Belt width cm})}}$$

Flow rates and belt speeds were measured during each experiment.

3.5.2 Particle size:

Particle size was analyzed using the Malvern Mastersizer X with a powder dispenser (X standard bench, Worcestershire, UK). The median value ($v_{0.5}$) was recorded. The median value of the particle size is the value which divides the distribution in two equal halves; 50% above and 50% below.

3.5.3 Particle size distribution:

Particle size distribution was obtained using the Malvern Mastersizer X with a powder dispenser (X standard bench, Worcestershire, UK). The particle uniformity value was used to evaluate the distribution. Uniformity of the particle is defined as a measure of the absolute deviation from the median size and was calculated using the following equation:

$$U = \frac{\sum X_i |d(x, 0.5) - d_i|}{d(x, 0.5) \sum X_i}$$

Where $d(x, 0.5)$ is the median size, d_i is the mean diameter and X_i the result of the size class i .

3.5.4 Powder chargeability:

Powder charge to mass ratio was measured using a Faraday cup system connected to an electrometer (model 602, Keithley Instruments Inc., Cleveland, OH,). 1 g of sample was run through the coating system. The sample was collected on the attached conveyor belt covered with a non-laminated brown paper. The sample was quickly transferred using a plastic spatula into the inner cup of the Faraday cup. The total charge was read and recorded. The inner cup located inside the Faraday cup was weighed before reading and after reading with the powder collected. The charge was then divided by the amount of powder to obtain a result in SI units ($\mu\text{C/kg}$).

3.5.5 Powder flowability:

Angle of repose was used to measure flowability of the powder. Powder was slowly transferred through a funnel with a 1.70 cm opening onto a petri dish with support. The petri dish was 3cm in diameter and the petri dish plus support was 1.7 cm in height. The tip of the funnel was placed at approximately 11cm from the dish. The peak of the pile of powder from the base of the petri dish to the top of the powder, obtained through the funnel was measured using a graduated ruler. This process was repeated until the highest peak was obtained. The angle of repose of the powder α was calculated with the following equation:

$$\alpha = \text{ARCTAN}(\text{peak height (cm)}/\text{dish radius (cm)}) * 57.$$

Results were analyzed using the following table:

Flow Characteristics	Angle of Repose(°)
Non flowing-cohesive	>60
Fairly free-flowing	45-60
Free-flowing	30-45
Excellent flowing	10-30
Aerated	<10

Table 3. 1: Flow characteristics of powders using angle of repose (Adapted from de Jong and others, 1999)

3.6-Color Measurement:

After approximately 30 min at room temperature, sample color was measured using a Minolta CR 300 colorimeter (Konica Minolta. Tokyo, Japan) using the

CIE L, a, b color scale. Measurements were taken on the coated surface and L, a, b values were recorded. The relationship between the three values was analyzed using delta E, Hue angle, browning index and chroma.

Delta E = $((L-L')^2 + (a-a')^2 + (b-b')^2)^{1/2}$ where a' is the average a value obtained from the control, b' is the average b value obtained from the control and L' is the average L value obtained from the control.

Hue angle = $\tan^{-1} (b/a)$

Browning index, BI = $\frac{[100(x - 0.31)]}{0.172}$, where $x = \frac{(a + 1.75 L)}{(5.645L + a - 3.012b)}$

Chroma = $(a^2 + b^2)^{1/2}$

3.7-Statistical Analysis:

Regression analysis was performed at an alpha level of 0.05 assuming equal variances using JMP software (Academic Version 4.03, SAS Institute, Inc., Cary, NC USA) on color variables, days to mold, and particle size. Color variables, days to mold, and particle size were the dependant variables and amount, method and particle size were the independent variables. Indicator variables were assigned to method where nonelectrostatic was represented as 0 and electrostatic as 1. An interaction variable was calculated and run as an independent variable.

Interaction = Amount or particle size * method.

A t test was also performed on evenness, transfer efficiency and charge to mass ratio.

3.8-Evenness:

Evenness was calculated by comparing the color reading taken from samples coated electrostatically and nonelectrostatically at two different locations on the French fries. Color measurements were compared by calculated %RSD, relative standard deviation or the evenness uniformity index of the color for electrostatic and nonelectrostatic coating. A t-test was used to compare the differences.

$$\%RSD = \frac{\text{Standard dev (color location 1, color location 2)}}{\text{Average (color location 1 and color location 2)}}$$

Uniformity index was also obtained using the following equation. $UI = 1 - (s / (1+s))$ where s is the standard deviation between the two color values obtained from the same French fries.

CHAPTER 4

RESULTS AND DISCUSSION

In order to determine whether electrostatic coating improved the functionality of powders, various aspects of the coating process were evaluated. Transfer efficiency, evenness of the process, particle size, particle size distribution, particle charge to mass ratio, powder flowability and tribocharging of the powder during transportation were examined for this study.

4.1 Transfer Efficiency:

Figure 4. 1: Transfer efficiency of electrostatic coating is higher than nonelectrostatic coating for all powders except cellulose with natamycin.

*** Significantly different ($p<0.05$).**

Transfer efficiency was significantly improved for glucose, smoke extract and sodium erythorbate when electrostatic coating was used (Fig 1). Increased transfer efficiency is common with electrostatic coating. Ratanatriwong and others (2003) reported transfer efficiency of seasonings onto potato chips was higher when electrostatic coating was used. Electrostatic coating was reported to have higher coating efficiency than nonelectrostatic coating for most powders (Ricks and others 2002, Biehl and Barringer 2004).

In order to evaluate the functionality of the powder applied using electrostatic and nonelectrostatic coating, products coated with the two methods must have the same amount of powder per piece. Since electrostatic coating deposits more powder on the food products, this effect had to be eliminated. Therefore, in this study the actual amount of powder was measured, to be able to make comparisons between the two methods with the same amount of powder per piece.

4.2 Glucose on French Fries, Smoke on French Fries, Sodium Erythorbate on Cheese:

4.2.1 Glucose on French fries:

For the same amount of powder on French fries coated with glucose, there was a significant difference in hue angle, L value, delta E and browning index between electrostatic and nonelectrostatic coating (fig 2-7, A1-A8). Electrostatic coating generates significantly redder French fries as indicated by higher a value and lower hue angle for electrostatic coating than nonelectrostatic coating. Electrostatic coating also produced significantly darker French fries with a lower L value compared to nonelectrostatic

coating. In addition, browning index and delta E were higher for electrostatic coating, translating to browner French fries with increased total color difference between the two methods.

Chroma and b value were not significantly different between the two methods of coating. Chroma indicates the saturation of the hue angle. The non significance of the chroma may be due to the color range at which these experiments were conducted. At a hue angle of 70° , which indicates a very high redness, L value of 50 which indicates a midpoint darkness, it is often very hard to obtain differences in chroma since the saturation level has already been reached. Rodriguez-Saona and others (1997) found chroma to have a quadratic relationship (from 32 to 45 and back to 32) with increasing reducing sugars. Saturation level was at a maximum at 100mg of reducing sugar/100g of tuber where the hue angle was 67° , and L value was 50. An increase in reducing sugars only decreased hue angle and L value and caused the chroma to decrease back to the initial level of 32. Consequently chroma may not be a good method of measurement of brownness for these samples because it has a very small range of variation.

The b value for electrostatic and nonelectrostatic coating was 31-33, indicating that the fries were yellow. However there was no difference between the two methods used during these experiments. A positive b value indicates yellow products which are the natural color of the tuber prior to cooking.

Figure 4. 2: Electrostatic coating with glucose produces darker French fries for the same amount of powder as nonelectrostatic coating.

Figure 4. 3: Electrostatic coating with glucose produces redder French fries for the same amount of powder as nonelectrostatic coating

Figure 4. 4: Electrostatic coating with glucose produces redder French fries for the same amount of powder as nonelectrostatic coating.

4.2.2 Smoke extract on French fries:

Figure 4. 5: Electrostatic coating with smoke extract produces darker French fries for the same amount of powder as nonelectrostatic coating.

Figure 4. 6: Electrostatic coating with smoke extract produces redder French fries for the same amount of powder as nonelectrostatic coating.

Figure 4. 7: Electrostatic coating with smoke extract produces redder French fries for the same amount of powder as nonelectrostatic coating.

There is a difference in how the two powders contributed to the browning of French fries. Glucose produced the same amount of browning for all powder amounts used in this study. Reducing sugars are often the limiting factor in browning of potatoes (Gray and Hughes 1978). This indicates that the diffusion rate of glucose to the amino acids is a limiting factor for the formation of brown compounds. On the other hand, extent of browning with smoke extract was dependant on concentration. This may be due to a greater diffusion rate, therefore creating browner French fries as powder amount increases. This difference in diffusion rate is partially due to the fact that glucose powder has the tendency to clump and flake off when there is a large amount on the French fries. Smoke powder does not clump or flake off, thus it has a better capability to infuse into the French fries.

4.2.3 Sodium erythorbate on cheese

Figure 4. 8. The shelf life of cheese coated with sodium erythorbate is significantly longer when electrostatic was used instead of nonelectrostatic coating. $p < 0.05$.

The shelf life of electrostatically coated cheese was longer than nonelectrostatic when the same amount of powder was used for both methods. Electrostatically, shelf life improved with increased amount of powder on the product. The improved shelf life of cheese observed with the addition of sodium erythorbate is probably due to the ability of the active ingredient to sequester oxygen and prevent spoilage. Sodium erythorbate has also been shown to decrease microbial counts when applied to kosher meats (Zuckerman and Mannheim 2000).

4.3 Evenness:

Greater functionality could be explained by increased evenness when electrostatic coating is used (Fig 9). During electrostatic coating, as powder particles land on the food, they are repelled by charged powders already coated on the food thus are directed to uncoated areas and spread evenly on the surface of the food. This creates more homogenous coating when electrostatic coating is used (Clark 1995). Strietelmeier and Reynolds (1969) found that an electrostatic salter produced salted crackers that had a lower average standard deviation of salt than those coated with the conventional method. Electrostatically coated potato chips were also found to have a smaller standard deviation in yellowness and were judged to have more even coating chips by a sensory panel (Ratanatriwong and others 2003).

The color was measured at different locations on the same French fry, coated with glucose or smoke extract electrostatically or nonelectrostatically (fig 10). Using % RSD (Relative standard deviation), or the evenness uniformity index, as a measure of

unevenness, electrostatic coating generated products that had significantly more even color when compared to nonelectrostatic coating. Electrostatically coated products were more even in redness indicated by hue angle and a value, in darkness indicated by L value, and in delta E and browning index (Fig 10, A.9-A.12).

The increased color produced by electrostatic coating may be due to a more even layer of powder, which is able to diffuse more evenly with the surface moisture to react with the amino acids. This would initiate the browning reaction uniformly over the surface area of the products. Whereas during nonelectrostatic coating, the powder does not coat evenly thus producing areas with and without browning resulting in scattered spots of color development.

Figure 4. 9: Electrostatically coated French fries had a more even color than nonelectrostatically coated French fries.

Figure 4. 10: Glucose and smoke extract showing is more even when coated electrostatically than nonelectrostatically.* significantly different ($p < 0.05$).

4.4 Charge to mass ratio:

Figure 4. 11: Charge to mass ratio of sodium erythorbate, glucose, and smoke extract is significantly greater with electrostatic coating while there is no difference for cellulose with natamycin.*Significantly different. ($p < 0.05$).

Charge to mass ratio is an important indicator to determine whether or not there will be an improvement seen with electrostatic coating. When there is a significant increase in charge to mass ratio electrostatic coating will produce higher transfer efficiency and a more even coating.

Charge to mass ratio is a measure of how much charge the powder has initially and how much it acquires during electrostatic coating. Smoke extract, glucose and sodium erythorbate had a significant increase in charge to mass ratio (Fig 11). All powders that showed a significant increase in charge with electrostatic coating had higher transfer efficiency, produced products that were more evenly and coated thus had greater color and longer shelf life (fig 1, 12). An increase in charge to mass has been shown to correlate to an increase in coating efficiency (Ratanatriwong and others 2003, Miller and Barringer 2002, Biehl and Barringer 2003). The increase in charge to mass ratio causes coating to be uniform by the fact that charged powder particles repel each other and spread across uncoated surfaces that have not previously been covered by the deposition of the earlier layer of powder.

4.4.1 Particle size and charge to mass ratio

Figure 4. 12: Charge to mass ratio of powder increases with decreasing particle size of glucose.

Figure 4. 13: Redness decreases with increasing particle size for both electrostatic and nonelectrostatic coating of 20mg of glucose on French fries.

Figure 4. 14: Redness decreases with increasing particle size for both electrostatic and nonelectrostatic coating of 20mg of glucose on French fries.

The initial charge to mass ratio is independent of size but the charge to mass ratio of the charged powder is dependant on size, as shown for glucose (fig 12). Smaller particles have a larger surface area therefore can develop higher charge to mass ratio than larger particles during electrostatic coating (Bailey 1998). Charge to mass ratio increases as salt size decreases (Miller and Barringer 2002). Increasing charge to mass ratio also increases coating efficiency during electrostatic coating with smaller particles in the tumble drum. (Biehl and Barringer 2004).

These results are closely related to the functionality of the food powders. As particle size decreases, charge to mass ratio increases and redness increases (higher a

value and lower hue angle) (Fig 13, 14). French fries were coated with several sizes of glucose powder and it was found that the smaller the size, the redder the finished product.

The improved functionality seen with these products during electrostatic and nonelectrostatic may be due to several processes. During nonelectrostatic coating the increase in browning seen with decreasing particle size may be due to the ability of smaller particles to dissolve faster on the surface of the French fry compared to larger particles. For electrostatic coating the decrease of color seen with larger particles is not only due to the ability of smaller particles to dissolve faster but also to the ability of smaller particles to acquire higher charge.

Evenness can be improved by increasing charge to mass ratio which is improved by decreasing particle size. However this process depends on the nature of the powder. Even though sodium erythorbate is bigger in size (161 μ m) than the biggest particle size (78 μ m) shown in fig 12, there was still an improvement seen with this powder.

4.5 Particle Size Distribution, Flowability, Tribocharging.

Other properties also influence whether a powder will show improved functionality with electrostatic coating. Particle size distribution of a powder can impact functionality by decreasing coating efficiency. Uniformity of the particle size distribution is a measure of the absolute deviation of size from the median size. Powders with a narrow distribution showed the most improvement with electrostatic coating (Table 4.1). Evenness of powder coating is better with smaller particle size and narrow particle size distribution (Bailey 1998). In addition, narrow size distribution is better during electrostatic coating to maintain a constant flow rate (Mazumder and others 1997).

Powder	Uniformity value	Angle of repose (°)	Flowability Description
Glucose	0.53	57.4	Fairly free flowing
Smoke extract	0.56	38.6	Free flowing
Sodium Erythorbate	0.68	56.8	Fairly free flowing
Cellulose with natamycin	0.88	73.4	Non flowing - cohesive

Table 4. 1: Particle size distribution, angle of repose and flowability description of glucose, smoke extract, sodium erythorbate, and cellulose with natamycin.

Powder flowability is also very important for the coating process. In order to have a uniform coating, the powder must flow through the coating equipment and be well dispersed while maintaining a uniform mass flow (Mazumder and others 1997). Glucose and smoke extract are fairly free flowing and free flowing powders respectively based on their angle of repose values (table 4.1). Sodium erythorbate also had a smaller angle of repose value thus is fairly free flowing. Free flowing powders deposit more effectively and are essential in maintaining uniform mass flow rate in order to optimize the coating process (Mazumder and others 1997). This is expected because it produced a significant improvement when used to coat cheese electrostatically.

During transportation when particles of different nature are together they tend to tribocharge creating opposite charge on each component due to powder-to-powder contacts (Murtomaa and Laine 2000). Two powder mixtures were used: smoke extract and cellulose with natamycin. Sodium erythorbate and glucose are pure compounds. Tribocharging of smoke extract during transportation did not however hinder the process because the powder was able to pick up enough charge to produce a significantly

different charge to mass ratio between electrostatic and nonelectrostatic coating. Tribocharging was probably minimized by silica used in this powder. Silica flow agents tend to destroy charge generation during tribocharging (Howell 2000). However tribocharging resulting in a charge that is the same as the charge of the corona used does not usually cause problems with electrostatic coating.

4.6 Reasons Why Powders May Not Show Improvement: Cellulose with Natamycin on Cheese:

Figure 4. 15. The shelf life of cheese coated with cellulose with natamycin was not different when electrostatic or nonelectrostatic coating was used.

The shelf life of cheese coated with natamycin was the same when electrostatic and nonelectrostatic coating was used (Fig 15). Natamycin is used to extend the shelf life of sliced cheese. It retards mold growth under ambient atmospheric conditions for 30 days (Suloff and others 2003).

Various theories could account for the reason why cellulose with natamycin did not show a shelf life extension with electrostatic coating. Cellulose with natamycin showed no significant increase in charge to mass ratio, had a wide particle size distribution, was cohesive and is very prone to tribocharging during transportation. The particle size of cellulose with natamycin was small, 42.7 μ m, which is included in the efficient range for electrostatic coating thus particle size was not a problem.

Cellulose with natamycin had an initial positive charge however negative polarity was used in these studies (fig 9). Improved coating efficiency is seen only when the polarity of the corona used is the same as the polarity of the initial charge created in the powder by tribocharging when the powder is run through the equipment (Sumawi and Barringer 2005). Therefore the powder did not show any improvement in charge to mass ratio and transfer efficiency indicating that electrostatic coating would not create more even coating.

The particle size distribution was wide for cellulose with natamycin powder (Table 4.1). The wide distribution of cellulose with natamycin could explain its poor performance during electrostatic coating. Evenness of powder coating is better with narrow particle size distribution during electrostatic coating (Bailey 1998). In addition it

was also found by Mazumder and others (1997) that narrow particle distributions perform better during electrostatic coating.

Cellulose with natamycin has an angle of repose of 73° which makes it a cohesive powder (table A.2). Cohesive powders have the tendency to aggregate which will hinder their ability to flow through the coating system and decrease the surface area able to pick up charge, thus decreasing their capacity to efficiently charge during electrostatic coating (Biehl and Barringer 2003).

For cellulose with natamycin, tribocharging was important in the overall charge of the powder. Tribocharging could have occurred during transportation of the powder. Cellulose only showed an improvement in transfer efficiency when a positive corona was used (Sumawi and Barringer 2005). Cohesive powders tend to have higher tribocharging value (Sumawi and Barringer 2005). During tribocharging cellulose could have picked up a positive charge and natamycin a negative charge. Since there is more cellulose in the mixture than natamycin, a first neutralization of both charges during transportation would generate an overall positive charge on the powder (Fig 11). In addition even though the powder was charged using a negative corona during electrostatic coating, a second neutralization process would have occurred again between negative and positive charges leaving the powder with a smaller overall positive charge (fig 11).

CHAPTER 5

CONCLUSION

To improve the functionality of a powder using electrostatic coating, various parts of the process and the powder have to be analyzed. First of all, properties such as particle size, distribution, flowability of the powder are very important. Smaller particle size is crucial to maintain higher transfer efficiency, better evenness, and better charge to mass ratio, thus an improved coating efficiency. Particle size distribution is also very important in maintaining a consistent process flow. Another variable that is important is the flowability. Particles need to be free flowing, because cohesive powders tend to aggregate and hinder the efficiency of the coating system. Finally for a powder mixture, it is important that tribocharging during transportation be minimized if the polarity of the charge generated is opposite to the corona used, for the powder to pick up additional charge during coating.

Using electrostatic coating to apply powders on products will result in a decrease in cooking time because products such as French fries will achieve the desired color faster than in the conventional method. In addition it also creates the opportunity to apply direct surface coating to French fries and obtain good color attributes without any

overuse of powder. Currently only infusion of solution or blanching is used to enhance color in French fries.

The application of antimycotic agents onto cheese is done via liquid media. These results can also create the opportunity for a direct application of the powdered antimycotic agents onto the surface of sliced cheese and obtain improvement in shelf life. This will help minimize wet surfaces on cheese which usually support the growth of mold and other spoilage microorganisms.

However, additional tests need to be done with the application of natamycin on cheese in order to determine the optimum coating conditions for this powder, to see improvement in shelf life with electrostatic coating. Results found in the study indicate that natamycin may generate improvement with electrostatic coating if a positive corona is used instead of negative.

REFERENCES

- Anon.1992. A look at electrostatic seasoners. *Snack foods*, December p16-17.
- Anon.1995. Sodium erythorbate, sodium isoascorbates applications. *Food Market & Tech* 9(2): 24-25.
- Anon.1996. New coats for old. *Food Manufact.* 71(5): 21.
- Bailey AG. (1998). The science and technology of electrostatic powder spraying, transport and coating. *J Electrostat*, 4(5): 85-120.
- Biehl H, Barringer SA. 2003. Physical properties important to electrostatic and nonelectrostatic powder transfer efficiency in a tumble drum. *J Food Sci* 68(8): 2512-2515.
- Biehl H, Barringer SA. 2004. Comparison of the effect of powder properties on coating transfer efficiency and dustiness in two nonelectrostatic and electrostatic system. *Innovative Food Sci and Emerging Tech* 5(2): 191:198.
- Chen L, Issenberg P.1972. Interactions of some wood smoke components with 5-amino groups in proteins. *J Agr. Food Chem.* 20: 1113.
- Clark G. 1995. Electrostatic coating technology for savoury snacks. *Food Tech Europe* 2(3): 90-96.
- Cross J. 1987. *Electrostatics: Principles, problems and applications*. Adam Hilger Publishing, Bristol, England. p 1-9.
- Davis JW. 2005. Idaho Potato A History of the Potato in Idaho. Viewed on 4/27/05. <http://radio.boisestate.edu/information/otherprojects/potato/fries.html>.
- de Jong JAH, Hoffmann AC, Finkers HJ. (1999). Properly determine powder flowability to maximize plant output. *Chem Eng Prog* 95(4): 25- 34.
- de Ruig WG, van den Berg G. 1985. Influence of fungicides sorbate and natamycin in cheese coatings on the quality of the cheese. *Neth. Milk Dairy J.* 39: 165-172.

- Eiora MNU, Rocha AL, Pfenning L. 1999. Degradation of potassium sorbate in vegetable spread by *Trichoderma harzianum rifai*. Dairy Food Environ Sanit 19:394-398.
- Elayedath S, Barringer S.A. 2002. Electrostatic powder coating of shredded cheese with antimycotic and anticaking agents. Innovative Food Sci. Emerging Tech, 3(4), 385-390.
- Finol ML, Marth EH, Lindsay RC. 1982. Depletion of sorbate from different media during growth of *Penicillium* species. J Food Prot 45:398-409.
- Friedman M. 1996. Food browning and its prevention: An overview. J Agric Food chem. 44(3): 631-653.
- Good H. 2004. Measure to assure the color stays right. Food Quality magazine. Feb 2004.
- Gray D, Hughes JC. 1978. Tuber quality. Potato crop. Chapman and Hall, London. p 504-544.
- Hendricks CD. 1973. Introduction to electrostatics, In electrostatics and its applications. Moore A.D. (Editor). Wiley-Interscience Publication, New York, 24-56.
- Hocking AD. 1997. Understanding and controlling mold spoilage in cheese, The Australian J. Dairy Technology, 52 (2): 123-124.
- Horinka PR. 1995. Powder particle size: its role in electrostatic charging. Powder Coating 4:51-56.
- Howell DM. 2000. The technology, formulation and application of powder coatings. JD Sanders, ed. John Wiley and Sons, New York. p 192-193, p 280-293.
- Hughes JF. 1984. Electrostatic powder coating. John Wiley & Sons, New York .
- Hughes JF. 1997. Electrostatic particle charging: Industrial and health care applications. Taunton, Somerset, England: Research Studies Press, Ltd.
- Husaini SA, Cooper GE. 1957. Fractionation of wood smoke and the comparison of chemical composition of sawdust and friction smoke. Food Technol 11:499.
- Hutchings JB. 1999. Food Color and Appearance. Aspen publishers Gaithersburg, MD. p227- 273.
- Igoe IS, Hui YH. 1999. Dictionary of food ingredients. Aspen publication Gaithersburg, MD. p127.

- Jay J. 1998. Modern food microbiology. Aspen Publishers, Gaithersburg, MD. p272-273.
- Kulkarni SG, Srinivasan RA, Dudani AT. 1968. Evaluation of some antifungal agents for use in dairy industry, Indian J Dairy Sci.21: 221-227.
- Lanigan RS. 1999. Final report on the safety assessment of ascorbyl palmitate, ascorbyl dipalmitate, ascorbyl stearate, erythorbic acid and sodium erythorbate. Intern J Toxicology 18(3):1-26.
- Law BA.1999. Technology of cheesemaking. CRC press, Boca Raton, Florida. p 22-25.
- Lisinska G, Leszczynsk W.1989. Potato Science and Technology. Elsevier Applied Science, N.Y. p165-232.
- Lucier G, Budge A, Plummer C, and Spurgeon C. 1991. U.S. Potato Statistics, (1949-1989). Statistical bulletin number 829, (p 127)., U.S.D.A Economic Research Service.
- Lund F, Filtenborg O, Frisvad JC.1995. Associated microflora of cheese. Food microbial 12:173-180.
- Malby LP, Enstad GG, De Silva SR. 1993. Investigation of the behavior of powders under and after consolidation. In Proceedings of symposium (reliable flow of particulate solids II) Oslo, Norway: EFCHE publication No 96, 23-25th August.
- Marquez G, Anon MC. 1986. Influence of reducing sugars and amino acids in the color development of fried potatoes. J Food Sci, 51(1):157-160.
- Mazumder MK, Wankum DL, Sims RA, Mountain JR, Chen H, Pettit P, Chaser T. 1997. Influence of powder properties on the performance of electrostatic coating process. J Electrostat, 40(41): 369-374.
- Miller MJ, Barringer SA. 2002. Effect of sodium chloride particle size and shape on nonelectrostatic and electrostatic coating of popcorn. J Food Sci 67(1): 198-201.
- Moore, A.D. (1968).Electrostatics. New York, Doubleday & Company Inc page. p 240.
- Murtomaa M, Laine E.2000. Electrostatic measurements on lactose-glucose mixtures. J Electrostat 48: 155-162.
- Nourian F, Ramaswamy HS, Kushalappa AC. 2003. Kinetics of quality change associated with potatoes stored at different temperatures. Lebensm-Wiss Technol, 36:49-65.

- Oostendorp JG. 1981. Natamycin. *Antonie Van Leeuwenhoek* 47: 170-171.
- Pannell RJH. 1980. Electrostatic coating of crisps and snack foods. *Confection Manuf. Mrktg* 17(6): 7-8.
- Peleg M. 1977. Flowability of foods powders and methods for its evaluation – a review. *J Food Process Eng* 1: 303-328.
- Peleg M, Hollenbach AM. 1984. Flow conditioners and anticaking agents. *Food Technol.* 5:95-98.
- Peleg M. 1987. Distribution of food powders. *The Manufacturing Confectioner* 67(6): 95-96, 98.
- Ratanatriwong P, Barringer SA, Delwiche J. 2003. Sensory preference, coating evenness, dustiness and transfer efficiency of electrostatically coated potato chips. *J Food Sci* 68(4): 1542-1547.
- Ricks NP, Barringer SA, Fitzpatrick JJ. 2002. Food powder characteristics important to nonelectrostatic and electrostatic coating and dustiness. *J Food Sci* 67(6): 2256-5563.
- Rodriguez-Saona LE, Wrolstad RE, Perieira C. 1997. Modeling the contribution of sugars, ascorbic acids, chlorogenic acids and amino acids to non- enzymatic browning of potato chips. *J Food Sci*, 62: 1001-1005.
- Sampuran-Singh BCO, Bright AW. 1978. A parametric study of electrostatic powder coating. *J Electrostatics* 4: 325-334.
- Seighman J. 2001. Snack foods seasonings. In: Lusas EW, Rooney LW. Editors. *Snack foods processing*. Lancaster Pa: Technomic Publishing Co p 495- 527.
- Smith O .1987. Potato chips. In WF Talburt and O Smith (eds) *Potato Processing*. 4th edition, AVI, New York. p382.
- Strietelmeier DM, Reynolds JW. 1969. On electrostatic salting. *Snack Food*. 58(9): 46-48.
- Suloff EC, Marcy JE, Hackney CR, Sumner SS, Bishop JR. 2003. Comparative study of a semisynthetic derivative of natamycin and the parent antibiotic on the spoilage of shredded cheddar cheese. *J Food Protect* 66(8): 1499-1502.
- Sumawi H, Barringer SA. 2005. Positive vs. negative electrostatic coating using food powders. *J Electrostat* 63(6-10): 815-821.

Teunou E, Fitzpatrick JJ, Synnott EC. 1999. Characterization of food powder flowability. *J Food Eng* 39:31-37.

Teunou E, Fitzpatrick JJ. 2000. Effect of storage time and consolidation on food powder flowability. *J Food Eng* 43: 97-101.

Vitaliano P. 2000. U.S. Cheese consumption in the decade ahead. *National Milk Producers Federation News* 6 (4).

Zamora R, Hinds FJ. 2005. Coordinate contribution of lipid oxidation and Maillard reaction to the nonenzymatic food browning. *Critical Reviews in Food Sci & Nutrition*. 45(1):11-49.

Zuckerman H, Mannheim CH. 2000. Color improvement of kosher beef using sodium ascorbate and erythorbate. *J Muscle Foods* 12: 137-151.

APPENDIX A

PRELIMINARY & RAW DATA

	Smoke extract		Glucose		Cellulose + natamycin		Sodium erythorbate	
	NE	E	NE	E	NE	E	NE	E
Study 1 Low	34.12	79.16	22.98	35.69	14.74	28.47	4.75	37.53
Study 1 Medium	40.22	96.32	36.19	75.84	10.34	33.30	39.72	48.73
Study 1 High	36.48	92.27	28.01	46.42	5.47	11.46	6.19	54.59
Study 2 Low	32.99	53.82	18.91	28.45	7.93	8.69	20.90	40.44
Study 2 Medium	28.81	50.67	14.76	64.37	10.88	29.24	8.36	11.35
Study 2 High	25.69	46.76	22.40		12.49	55.97	36.99	57.21
	p value	Size	p value	Size	p value	Size	p value	Size
	0.007	34.70µm	0.037	37.60µm	0.056	47.20µm	0.039	161.26µm

Table A. 1: Transfer efficiency (%) of all powder with electrostatic coating and nonelectrostatic coating.

Figure A. 1: Browning index of glucose applied onto French fries

Figure A. 2: Delta E of glucose applied onto French fries

Figure A. 3: b value of glucose applied onto French fries

Figure A. 4: Chroma of glucose applied onto French fries

Figure A. 5: Browning index of smoke extract applied onto French fries

Figure A. 6: Delta E of smoke extract applied onto French fries

Figure A. 7: b value of smoke extract applied onto French fries

Figure A. 8: Chroma of smoke extract applied onto French fries

Figure A. 9: %RSD of a value showing significant difference between electrostatic and nonelectrostatic coating. * Significantly different ($p < 0.05$).

Figure A. 10: %RSD of L value showing significant difference between electrostatic and nonelectrostatic coating. * Significantly different ($p<0.05$)

Figure A. 11: %RSD of Delta E showing significant difference between electrostatic and nonelectrostatic coating. * Significantly different ($p<0.05$)

Figure A. 12: %RSD of Browning index showing significant difference between electrostatic and nonelectrostatic coating. * Significantly different ($p < 0.05$)

Figure A. 13: %RSD of Browning index showing significant difference between electrostatic and nonelectrostatic coating. * Significantly different ($p < 0.05$)

	Glucose		Smoke Extract		Cellulose with natamycin		Sodium erythorbate	
Height(cm)	3.91	4.2	2.81	2.99	6.51	6.98	3.9	4.1
Dish + support(cm)	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Radius(cm)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Peak (cm)	2.21	2.5	1.11	1.29	4.81	5.28	2.2	2.4
Angle of repose (deg)	55.8	59.0	36.5	40.7	72.6	74.1	55.7	57.9
Average	57.4		38.6		73.4		56.8	

Table A. 2: Flowability of powders

Smoke extract			Glucose		
Obs(%)	Res(%)	D(v,0.5)um	Obs(%)	Res(%)	D(v,0.5)um
12.4	0.174	34.42	12.2	0.165	37.47
25.6	0.202	34.91	13.4	0.167	37.87
23.5	0.252	34.77	11.7	0.175	37.57
	Average	34.70		Average	37.63
Sodium erythorbate			Cellulose with natamycin		
Obs(%)	Res(%)	D(v,0.5)um	Obs(%)	Res(%)	D(v,0.5)um
13.7	0.546	161.93	16.4	0.173	46.97
9.6	0.359	162.32	16.2	0.171	46.88
8.4	0.205	159.54	16.2	0.174	47.75
	Average	161.26		Average	47.20

Table A. 3: Particle size of all powders

Method		Glucose (μm)				
		77.97	66	52	37.63	33
E	Average	-11.60	-17.02	-9.8194	-11.3	-
	Stdev	1.023	1.459	2.005	0.723	4.160
NE	Average	-44.91	-31.09	-41.83	-78.20	-
	Stdev	7.541	3.360	6.217	10.50	68.40
		Smoke extract	Sodium erythorbate	Cellulose Natamycin		
E	Average	-11.72	-20.14	4.607		
	Stdev	0.5942	3.168	0.768		
NE	Average	-42.54	-30.27	4.531		
	Stdev	11.05	3.354	2.171		

Table A. 4: Charge to mass ratio ($\mu\text{C/Kg}$) of glucose, smoke extract, sodium erythorbate, and cellulose with natamycin

Smoke Extract Study 1						
	NE 1	NE 2	NE 3	E 1	E 2	E 3
Belt Speed(cm/min)	45.72	45.72	45.72	88.9	88.9	88.9
Flow rate(g/min)	5.482	6.934	9.961	5.482	5.912	6.934
Accurate Setting	0	1	2	0	0.5	1
Smoke Extract Study 2						
	NE 1	NE 2	NE 3	E 1	E 2	E 3
Belt Speed(cm/min)	45.72	45.72	45.72	88.9	88.9	88.9
Flow rate(g/min)	5.708	6.895	10.34	5.708	6.067	6.895
Accurate Setting	0	1	2	0	0.5	1
Glucose Study 1						

	NE 1	NE 2	NE 3	E 1	E 2	E 3
Belt Speed(cm/min)	45.72	45.72	45.72	55.88	55.88	55.88
Flow rate(g/min)	3.7	5.616	7.2	3.13	3.7	4.2
Accurate Setting	1	2	3	0	1	1.5
Glucose Study 2						
	NE 1	NE 2	NE 3	E 1	E 2	E 3
Belt Speed(cm/min)	45.72	45.72	45.72	55.88	55.88	55.88
Flow rate(g/min)	4.757	7.195	10.34	3.554	4.757	5.126
Accurate Setting	1	2	3	0	1	1.5
Sodium erythorbate study 1						
	NE 1	NE 2	NE 3	E 1	E 2	E 3
Belt Speed(cm/min)	95	95	95	95	95	95
Flow rate(g/min)	30.64	45.17	50.14	30.64	45.17	50.14
Accurate Setting	3	3+1	3+2	3	3+1	3+2
Sodium erythorbate study 2						
	NE 1	NE 2	NE 3	E 1	E 2	E 3
Belt Speed(cm/min)	20.32	20.32	20.32	20.32	20.32	20.32
Flow rate(g/min)	2.713	4.950	3.504	5.735	9.071	4.950
Accurate Setting	1	2	3	0	1	1.5
Powdered cellulose study 1						
	NE 1	NE 2	NE 3	E 1	E 2	E 3
Belt Speed(cm/min)	40.64	40.64	40.64	40.64	40.64	40.64
Flow rate(g/min)	7.388	7.388	5.9344	2.417	1.594	0.8038
Accurate Setting	6	6	5	1	0.5	0
Powdered cellulose study 2						
	NE 1	NE 2	NE 3	E 1	E 2	E 3
Belt Speed(cm/min)	40.64	40.64	40.64	55.88	55.88	55.88
Flow rate(g/min)	3.890	4.829	5.766	1.714	3.108	2.103
Accurate Setting	4	5	5.5	1	2	1.5

Table A. 5: Experimental conditions. Belt width was 30cm and sample area for french fries was 6.4516cm² and was 22.5 cm² for cheese

APPENDIX B

STATISTICAL ANALYSIS

Smoke Extract with French fries			
p value			
Variable	Method	Amount	Interaction
a	<0.001	<0.001	<0.001
b	0.54	0.12	0.71
L	<0.001	<0.001	<0.001
Hue	<0.001	<0.001	<0.001
Browning	<0.001	<0.001	<0.001
Delta E	<0.01	<0.001	<0.001
Chroma	0.96	0.91	0.89

Table B. 1: Regression analysis of color variable vs amount, method, and interaction for electrostatically coated French fries vs nonelectrostatically coated French fries

Glucose with French fries			
p value			
Variable	Method	Amount	Interaction
a	<0.001	0.24	-
b	0.94	0.52	-
L	<0.001	0.94	-
Hue	<0.001	0.44	-
Browning	<0.001	0.33	-
Delta E	<0.001	0.52	-
Chroma	0.47	0.62	-

Table B. 2: Regression analysis of color variables vs amount, method, and interaction for electrostatically coated French fries vs nonelectrostatically coated French fries

Sodium erythorbate on cheese			
Variable	Method	Amount	Interaction
Days	<0.0001	0.0081	<0.0001
Cellulose with natamycin on cheese			
Variable	Method	Amount	Interaction
Days	0.1061	<0.0001	<0.0001

Table B. 3: Regression analysis of shelf life in days vs amount, method, and interaction for electrostatically coated cheese vs nonelectrostatically coated French fries.