



The influence of particle size on separation and dustiness in powder mixtures during nonelectrostatic and electrostatic coating



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ABSTRACT

Common food powders and their mixtures, consisting of two powders with the same composition but different in particle size: fine (51–95 μm) and coarse (244–401 μm) NaCl, KCl, sucrose, rice starch, maltodextrin, whey protein, casein and soy protein, were coated on a target at 0 and -25 kV. Over half of the mixtures showed separation due to a difference in particle size. Separation was caused by the difference in individual transfer efficiency of the powders and interactions during coating. Both composition and differences in size were found to be important. Being in a mixture did not change the amount of dust formed.

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1. Practical applications

A mixture containing different size powders has a propensity to separate. The separation was caused by the difference in individual transfer efficiency of powders in a mixture and/or the interaction between the powders. To reduce the difference in individual transfer efficiency and effect of interaction, powders with similar size should be used. However, the effect of compositional differences also needs to be considered. Coating parameters such as air velocity could be optimized to decrease the differences in individual transfer efficiency and interactions. Additionally, adjusting the proportion of original powders in the mixture may be needed to achieve the desired taste.

2. Introduction

Many foods, especially snack foods, are coated with powdered seasonings in order to enhance their flavor and increase product variety. A seasoning is usually a mixture of at least two powder ingredients because of the unique function of each ingredient. The most commonly used ingredients are salt, filler such as maltodextrin and corn flour, dairy powders such as cheese powders or sour

cream powders, dehydrated vegetable powders, spices, compounded flavors, flavor enhancers, sweeteners, acids, color, processing aids such as vegetable oil or silicon dioxide, and antioxidants [14]. In spite of the high frequency of use, research related to coating characteristics with powder mixtures is still limited.

Separation of powder in a mixture is undesirable. Separation can negatively affect flavor and appearance of the final product. While the composition of the powders contributes to the separation of mixtures [6], particle size has been reported to cause separation in a mixture as well [15,20]. Differences in particle trajectory cause the separation in the mixture containing powders with different size. Coarse powders fall faster than fine powders because of gravity force and miss the target, leading to separation [20]. Greater transfer efficiency for coarse powders than fine powders due to gravity force was also found by others [8,13,19]. Not only differences in targeting loss cause separation, but also the differences in adhesion loss cause separation, particularly when the mixture is coated electrostatically [15]. Finally, differences in dust production also contribute to loss and separation of the powders.

Most powders used for coating are very small and cause dust during coating. Dust is undesirable because it causes powder waste, overuse of powders, additional time and cost for cleaning, and respiratory distress to the employees. Several physical properties affect dustiness [11,13]. With decreasing particle size and density, dustiness increases [11,13]. As the powder becomes more cohesive,

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dustiness decreases [11]. Although there are no studies on the effect of food powder mixtures on dustiness, electrostatic coating is generally known to be efficient in reducing dust during powder coating [3,11,13].

Electrostatic powder coating has been used to improve the coating performance. It has been shown to reduce powder loss, produce more even distribution and reduce the amount of dust [10]. During electrostatic coating, powders pass through the corona discharge area, where the intense voltage gradient ionizes the air around the negative electrode, and are charged by negative ions. The charged powders are accelerated by electrostatic force according to Coulomb's law to deposit onto the nearest grounded target [1]. Gravitational force, which depends on the powder mass, and electrostatic force cause powders to deposit on food products, resulting in an increase in transfer efficiency [3,9,21] and a reduction of dust [3,11,13]. Even though electrostatic coating is more efficient than nonelectrostatic coating in individual coating, it can increase separation when mixtures are coated. In a mixture of coarse and fine powders, differences in adhesion loss increase the separation. Fine powders with a higher charge adhere well on the target and increase the adhesion loss of coarse powders by creating a charged layer and repelling the incoming coarse powders [15]. However, in a mixture with similar size powders, using electrostatic coating decreased separation by decreasing targeting loss and adhesion loss of powders in the mixture [6,16].

The objective of this study was to determine whether separation occurs when a mixture containing different sizes of powder was coated nonelectrostatically and electrostatically. The causes of the separation: differences in individual transfer efficiency and the interaction of powder during coating were determined. In addition, the amount of dust generated was measured during coating powders individually and coating as a mixture.

3. Materials and methods

3.1. Powder sample

The mixtures used in this study consisted of two powders with the same composition but different in particle size: fine and coarse. The fine powders were NaCl (325 Extra fine salt, Morton International Inc., Chicago, IL, U.S.A.), KCl (Fisher Scientific, Fair Lawn, NJ, U.S.A.), powdered sugar (Dixie Crystal, Sugar Land, TX, U.S.A.), rice starch (National starch and chemical Ltd., Thailand) Maltodextrin (Maltrin M700, GPC, Muscatine, IA, U.S.A.), whey protein isolate (Proliant, Iso-Chill 9000, Ames, IA, U.S.A.), casein (acid casein 720, Fonterra, Rosemont, IL, U.S.A.), and soy protein (toasted soy grits, ADM, Decatur, IL, U.S.A.). Among these eight powders, KCl, rice starch, maltodextrin, whey protein, casein and soy protein were ground using an ultra-centrifugal mill (ZM100, Retsch GmbH & Co.KG, Clifton, NJ, U.S.A.) three times at 18,000 rpm to reduce particle size. The coarse powders were NaCl (Alberger flake salt, Cargill Inc., Minneapolis, MN, U.S.A.), KCl (Sigma–Aldrich, St. Louis, MO, U.S.A.), granulated sugar (Domino, Yonkers, NY, U.S.A.), rice starch, maltodextrin, whey protein isolate (Proliant, Iso-Chill 9010, Ames, IA, U.S.A.), casein and soy protein. The mean diameters of the powders were measured using the Malvern Mastersizer (X standard bench, Malvern Instrument Ltd., Worcestershire, U.K.). The volume mean diameter $D[4,3]$ of each powder was reported. Because the water activity of the powder has been shown to affect the coating efficiency, the powders were equilibrated over saturated magnesium chloride solution (32.8% relative humidity) in sealed desiccators until used. The mixtures contained 20 g of the fine powder mixed with 20 g of the coarse powder. Forty grams of each powder were used for individual coating.

Angle of repose was used to measure the flowability of the powders. It was determined by the modified fixed base method using a 2.81-cm diameter and 1.22-cm high Petri-dish. Powders were sifted with a powder sifter through a funnel with its tip 11 cm from the top edge of the Petri-dish. The maximum peak height of the powders prior to collapse was measured by a caliper and recorded. The arctangent of the peak height over the radius gives the angle of repose.

Resistivity of the powders was measured using a powder resistivity test cell. The powder test cell was filled with 5 cm³ of the powder. Air was dispelled by tapping the cell for 5 s. Voltage (125 V) was applied to the cell via a high-voltage supply unit. The current value was read from the electrometer when there was no change over a 15-s period. Resistivity was calculated using $(K \times I)/V$, where K represents the cell constant (0.014); I represents electrical current; (A) and V represents the voltage applied (V).

Tapped density was used to measure the powder density. In this study, the fine and coarse powders are identical in composition and the fine powders were assumed to have similar size and shape with the no internal pore volume. Tapped density of fine powders was determined by sifting the powder (120 ± 10 g) into a 250-mL graduated cylinder. The powder in the cylinder was weighed and tapped 200 times by a tapped density tester. Tapped density was calculated by dividing powder weight (g) by tapped volume (cm³).

3.2. Coating process

An electrostatic powder-coating machine (Terronics Development Corp., Elwood, IN, U.S.A.) was used to coat the food powders on an aluminum tray (Fig. 1). A previous study found that targeting loss is the main factor in powder loss during coating but there was little effect of adhesion loss [6]. Thus this study focused only on the targeting loss. Adhesion loss was prevented by using a tray with a 2 cm height edge as a target. No voltage was applied for non-electrostatic coating and -25 kV was used for electrostatic coating. An air compressor (Hitachi EC79, Hitachi Koki Co., Ltd., Tokyo, Japan) was used to supply airflow to drive the powder through the coating chamber. All experiments were carried out at 30–35% relative humidity and 20–25 °C. Either individual powders or mixtures (40 g) were blown through the coating chamber at an air velocity of 3.3 m/s. A vibratory feeder (Syntron Magnetic Feeder, Model FTO-C, FMC Corporation, Homer City, PA, U.S.A.) was used to control the consistency of the powder feeding.

3.3. Determination of the amount of powder in a mixture after coating

In order to identify how much fine and coarse powders were in the deposited mixture, the cutoff particle size (particle size used to differentiate fine powder from coarse powder) was determined using the malvern mastersizer. The fine and coarse powders were individually measured to determine their particle size distribution. The cut off particle size was selected to produce the least overlap or error of percent fine and coarse powders when coated individually. To ensure that the selected cutoff also works for a mixture, the cutoff was tested with mixtures of the known concentration. The error produced by using the cut off was between 0 and 10%. Particle size distribution of NaCl is presented as an example (Fig. 2).

3.4. Separation

Separation was defined as a significant change in percentage between fine and coarse powders from the percentage entering the coating chamber, which was 50:50%. The amount of fine and coarse powders on the target when they were coated individually was

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