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Electrohydrodynamic spraying quality of different chocolate formulations

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ABSTRACT

The objective of this research was to determine the effect of ingredients in chocolate (cocoa liquor, cocoa butter, sucrose, milk powder) and tempering on electrohydrodynamic spraying quality. As cocoa butter increased, the droplet size generally decreased, because the viscosity decreased. As cocoa liquor increased, the droplet size and resistivity decreased and then increased, while the viscosity only decreased. Similarly, as sucrose decreased and milk powder correspondingly increased, the droplet size decreased, because the resistivity decreased, but the viscosity did not change. The droplet size and viscosity of chocolate increased during tempering, but the resistivity did not change.

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1. Introduction

Chocolate is one of the most popular snacks around the world. It has a smooth texture and good taste, so it is widely used as a coating material in the snack food and confectionary industries. Edible films play an important role in food shelf-life by preventing food contacting its environment. Films can stop moisture migration, improve sensory attributes and decrease the growth of microbes. Food additives, such as antioxidants, pigments and sweeteners, can also be added into the edible films on foods [1,2]. Besides chocolate, proteins, polysaccharides and lipids are also used as coating materials to isolate water and air exchange [3]. The main ingredients of chocolate include sucrose, cocoa butter, cocoa liquor, milk powder and lecithin, which all influence its cost. Therefore, weight control should be accurate during the coating processing in order to reduce cost [4].

Electrohydrodynamic spraying (EHD) is frequently used to spray liquid into small droplets by electrostatic force. Electrostatic coating of liquid seasonings produces more uniform coating and higher flavor intensity than non-electrostatic coating [5]. Besides chocolate, EHD is used to coat food with oils, emulsifiers and flavors [6]. The electrostatic spraying droplet size for liquid chocolate varies from 0.1 to 1000 μm [7]. Using finer droplets increases coverage evenness and reduces waste, therefore reducing cost [8].

Tempering is an important process to create the correct crystallization forms of cocoa butter in the chocolate suspension. The viscosity of tempered chocolate is increased by increased crystal type V [9]. There are six crystal forms for fat in cocoa butter. The main purpose in tempering progress is to produce fat in crystal form V which has the most desirable stable texture and appearance. When chocolate is added with small fat crystals (seeds) at 34 °C, the plastic viscosity increases [10].

Among the physical properties, resistivity and viscosity are the two most important parameters to affect the spray quality [7]. The electrostatic spray quality is determined by the resistivity and viscosity of the sample, which are determined by the ingredients of the chocolate.

Resistivity influences the spray quality. Resistivity is affected by temperature and ions in the chocolate [8]. The resistivity is also affected by the ingredients in the samples. Increasing sugar content in chocolate increases resistivity [11]. Increasing cocoa liquor and decreasing cocoa butter increases resistivity [7]. Increasing the resistivity of chocolate increases coating thickness [6]. In one study, the oil only atomized when the resistivity of the liquid was between 10^5 and $10^9 \Omega^*$m [12]. In order to achieve this range, emulsifiers such as lecithin and alcohols can be added into the liquid to decrease the resistivity. The resistivity for chocolate is about $10^9 \Omega^*$m [7], which is in the correct range to atomize.

The coating thickness of chocolate decreases with decreasing viscosity, and viscosity decreases with increasing cocoa butter [6].

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Cocoa butter decreases the viscosity [7]. Fat in chocolate is the continuous phase in which particles are suspended, thus increasing fat increases continuous phase and decreases viscosity [13]. Increasing sugar content in chocolate increases the viscosity [11].

The objective of this research is to determine the effect of varying the concentration of each chocolate ingredient and the tempering on electrostatic spraying quality. Viscosity and resistivity of the chocolate were measured to determine their effect on the droplet size. A small droplet size indicates better spray quality, because smaller droplet produces more even and thinner continuous barrier.

2. Materials and methods

2.1. Sample preparation

Chocolate was made with different proportions of the key ingredients. The lecithin (American Lecithin Company, Oxford, CT, USA) was controlled at 0.5% by weight for all samples. The cocoa butter (SaaQin Inc., Hicksville, NY, USA) was melted in a hot water bath at 55 to 60 °C and transferred into a concher (Alchemist's Stone Chocolate Melanger, Oakland, OR, USA) along with the lecithin, sucrose (Domino Sugar Factory, Brooklyn, NY, USA), cocoa liquor (Kraft Food, Northfield, IL, USA), and nonfat milk powder (The Kroger Co., Cincinnati, OH, USA), and conched for 8 h. The finished product was poured into a Pyrex glassware storage container and cooled in the refrigerator. The cooled sample was then cut into pieces and stored in a ziplock bag at 4 °C. Each batch was 1500 g. For tempered samples, chocolate was tempered using a temperer (ChocoVision Corp, Poughkeepsie, NY, USA). Hershey's milk chocolate (The Hershey Company, Derry Township, PA, USA) was used as seed chocolate. The ingredients for each sample are showed in Table 1.

2.2. Resistivity

The electrical resistivity was measured using a resistivity cell, electrometer (614 Electrometer, Keithley Instruments Inc. Cleveland, OH, USA) and a voltmeter (ABC 125-1DM, KEPCO Programmable Power Supply, Seoul, Korea). Approximately 125 g milk chocolate was placed into a 250 ml beaker (about half of the volume) and heated by hot plate to the desired temperature (30 °C) and then put into the resistivity cylinder. The cylinder was filled carefully to avoid any air gaps. The voltage was adjusted to 125 V and the current was read from the electrometer after the reading stabilized, which took 10–30 s. Three replicates were tested.

The resistivity of the sample was calculated using:

$$\text{Resistivity} = (\text{k} \times V)/I$$

where k is 0.014, the cell constant of the cell, V is the voltage applied and I is the current.

The bulk density of chocolates were measured by using a 10 ml volumetric flask and balance. It was calculated using:

$$\text{Bulk density} = w/v$$

where w is the weight of sample and v is the volume.

2.3. Viscosity

Viscosity was measured using a Brookfield RVDV-II+ Viscometer (Brookfield Engineering Laboratories Inc., Middleboro, MA, USA) using spindle 4.400 g sample was put in a 600 ml beaker and was pre-sheared for 3 min at 50 rpm before recording the viscosity values. The spindle was rotated over all speeds. The viscosity value was recorded by decreasing the spindle speeds from 100 to 0 rpm followed by an increase. The viscosity was measured at 30 °C. The temperature of the sample was maintained by controlling the temperature of the water bath. As chocolate is a shear-thinning fluid, the viscosity for all samples was compared when the speed of spindle was at 10 rpm (average value for increasing and decreasing speed). Three replications were performed.

2.4. Spraying

The samples were coated using a TDC Liquid Electrostatic Coater (Terronics Development Corporation, Elmwood, IL, USA). The samples were sprayed at -25 kV. The sample was pumped to the slot nozzle (150 mm by 0.4 mm) using a variable speed pump (Cole-Parmer Instrument Company, Vernon Hills, IL, USA). The speed is controlled at the maximum flow rate of 250 mL/min. The inlet and outlet tubes of the pump were insulated and heated to 30 °C by a variable autotransformer (The Superior Electric Co., Bristol, CT, USA). The samples were sprayed onto a 16 × 18 cm glass slide, maintained at room temperature, placed on a conveyer belt moving at a speed of 1.7 cm/s. The nozzle was 13 cm above the conveyor belt. Three replications were performed for each sample.

Table 1
The ingredients for all samples.

Samples	Sucrose (% w/w)	Milk (% w/w)	Cocoa butter (% w/w)	Cocoa liquor (% w/w)
CB25	27.5	27.5	25	19.5
CB30	25	25	30	19.5
CB35	22.5	22.5	35	19.5
CB40	20	20	40	19.5
CB45	17.5	17.5	45	19.5
CL0	32.25	32.25	35	0
CL9.5	27.5	27.5	35	9.5
CL14.5	25	25	35	14.5
CL19.5	22.5	22.5	35	19.5
CL24.5	20	20	35	24.5
CL29.5	17.5	17.5	35	29.5
S0M45	0	45	35	19.5
S25M20	25	20	35	19.5
S30M15	30	15	35	19.5
S35M10	35	10	35	19.5
S40M5	40	5	35	19.5
S45M0	45	0	35	19.5