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Effect of spray-drying process on physical properties of sodium chloride/maltodextrin complexes

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ABSTRACT

The mixture of sodium chloride and maltodextrin was processed by spray-drying with various inlet temperatures (130, 140, 150, 160 and 170 °C) or atomization pressure (60, 100, 140, 180 and 220 kPa). Physical properties of spray-dried maltodextrin/NaCl powder were characterized such as surface area or morphological images and sensory evaluation was carried out to observe saltiness of maltodextrin/NaCl complexes. At the high atomization pressure produced smallest particle of maltodextrin/NaCl complexes and it was effective to be melted faster and then saltiness was also rapidly recognized compared with bigger complexes. In this study, although inlet temperature was not effective like atomization pressure processing, relatively lower inlet temperature influenced on maltodextrin/NaCl complexes during spray-drying. It was suggested that decrease of salt particle size could improve melting speed and it could be helpful to enhance intensity of saltiness with small amount of salt.

1. Introduction

Sodium is a taste compound that is commonly used to prepare bread, meat products, pickles, dairy products, and so on. Sodium preserves food, contributes to food structure, and also gives food a salty taste. Furthermore, sodium is one of the most important minerals that the human body uses to maintain homeostasis since osmotic pressure and regular blood pH levels are affected by sodium. Sodium is also important for muscles and nerves to function since it assists both muscular contraction and the transmission of nerve signals, and it helps in the absorption of glucose, amino acids, water, and chloride in the small intestine [1–3]. However, an excessive sodium intake is also detrimental to health because it is associated with an increased risk for high blood pressure, osteoporosis, heart disease, and stroke [4–6].

A number of governments, and organizations such as WHO and the FDA, have introduced regulations to reduce the sodium intake in the population [7-9]. As a result, many researchers have investigated methods to reduce sodium contents in food by using sodium chloride replacements, such as KCl, MgCl, $MgSO_4$, or $CaSO_4$, or a salty enhancer such as Kokumi or Umami [10–15]. When sodium chloride is dissolved, it induces a salty taste in the mouth. If the salt crystals have a very small size, a particular crystal shape (cubic, dentitric, etc.), and a large contact or exposed surface, salt can be rapidly dissolved in the mouth, producing a higher salty intensity [14,15]. Therefore, small-sized salt crystals can be used in a lower concentration than conventionally-sized crystals. For example, Desmond [16] demonstrated that vacuum-granulated dentitric salt (macroporous crystals) and "cubic" salt dissolve almost twice as fast as conventional salt does. However, few studies have investigated the reduction of sodium contents or the enhancement of a salty taste by modifying the physical properties of the sodium crystals, such as the shape, particle size, and surface area.

The change in the chemical structure of a compound may influence its taste, making it sweet, bitter, astringent, and so on. The structure of a compound may change as a result of heating, drying, or adding a material. In particular, drying is an effective method to modify the physical properties of an original material. Spray-drying is an effective process commonly used in the pharmaceutical and food industries to produce a powder form that is comprised of micro- or nano-sized particles [17–20]. In order to dry a liquid sample, a four-step process takes place, including atomization, spray-air contact, evaporation, and product recovery, in that order. In the atomization step, the liquid sample is dispersed by using an atomizer or a spray nozzle to control the size of the drops. The drying temperature (inlet temperature, outlet temperature), sample flow rate, and blowing power also affect the physical properties of the final products [21–23]. The atomization power and the inlet temperature are the elements that affect the final quality of the product the most. The atomizer has been described as the most important part of a spray-dryer, and its purpose is to create finer droplets by controlling the provided pressure or centrifugal energy. Namely, the atomization power

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influences the heat that is transferred at the surface between the dry air and the liquid [24]. The inlet temperature is also a critical element in spray-drying. Zbicinski et al. [25] found that inlet temperature is directly proportional to both the rate at which the sample dried and the final water content. For example, a high water content, poor fluidity, and ease of agglomeration were caused at low evaporation rates.

The main purpose of this study was to find best conditions for the formation of salt enhancing the salty taste. Spray-drying was used to change the physical properties of sodium chloride, such as the shape, particle size, and surface area, by adjusting the atomization power and the inlet temperature. Maltodextrin was used as a carrier matrix during spray-drying, and then the surface area of the spray-dried salt complexes was determined, and the sensory property was evaluated, with a particular focus on saltiness.

2. Materials and methods

2.1. Preparation of the maltodextrin/NaCl complex

20% (*w*/*v*) of NaCl (Taepyungsalt Inc., Korea) and 10% (*w*/*v*) maltodextrin (MD, dextrose equivalent: 15–20, Weifang Codi Imp. & Exp. Co., Ltd., China) were completely dissolved in distilled water by using a magnetic stirrer at 500 rpm for 30 min. First, the mixture was spray dried by using a spray dryer (SD-1000, Eyela, Miyagi, Japan) with different inlet temperatures (130, 140, 150, 160, and 170 °C) and an atomization pressure of 100 kPa in order to identify the optimum drying temperature. Then, the atomization pressure was adjusted (60, 100, 140, 180, and 220 kPa) while using the optimum inlet temperature. During spray-drying, the blow power and the sample feeding rate were fixed to 0.6 (m^3/min) and 500 (mL/h), respectively, according to a previous test. The outlet temperature was also automatically controlled to be 80–90 °C below that of the inlet temperature. The optimum spray-drying condition was decided according to the results of the average surface area of maltodextrin/NaCl complex or a sensory evaluation.

2.2. Surface area measurement

The structure of the maltodextrin/NaCl complex was observed by using a microscope (Olympus CX31, Olympus Corp., Japan), and the surface area was measured by using an imaging tool (UTHSCSA, The University of Texas Health Science Center in San Antonio, Texas, USA). Over 100 particles were captured in one image in order to calculate the average surface area.

2.3. Scanning electron microscopy (SEM)

The maltodextrin/NaCl complex was observed using a scanning election microscope (FE-SEM, S-4700, Hitachi, Tokyo, Japan). All of the samples were coated with gold for 40 s via ion sputtering (E-1010, Hitachi, Tokyo, Japan) at a current of 15 mA.

2.4. Analysis of the sensory properties

In order to train the cognitive ability for the perception of a salty flavor, 18 panels were trained by using a ranking test with various concentrations of NaCl in solution, ranging from 25 mmol to 80 mmol. For the ranking test, the samples were evaluated and placed in a ranked order according to the sensory intensity [26]. As seen in Table 1, a specific number of samples was prepared at each stage, and then the panels decided the order of the samples according to the intensity in the perception of a salty taste after the sensory test, and as the stage increased, the panel's cognitive ability for the perception of a salty taste had been trained. Through repetitive training, the cognitive ability of the panels improved for the salty taste. The, the 18 panels that were trained evaluated the salty intensity in order of the recognition of saltiness (salty cognitive speed) and melting rate of the various maltodextrin/NaCl complexes produced. 30 mg of each sample was protect from exposure to oxygen and was served to the panel. Then, the panel swallowed a 30 mg sample in one go. The panels rinsed their mouth, and then took a 3 min break after testing each sample. The data were analyzed through an ANOVA in the SAS statistical program, version 9.2 (SAS Institute, Cary, NC), and the differences among the means were compared using Duncan's multiple range tests ($p < 0.05$).

Table 1
Various concentrations of NaCl solution used for panel training during the sensory evaluation.

Stage	Number of samples	NaCl solution (mmol)
1	4	30, 50, 60, 80
2	6	30, 40, 50, 60, 70, 80
3	8	30, 35, 40, 45, 50, 60, 70, 80
4	10	30, 35, 40, 35, 50, 55, 60, 65, 70, 80
5	12	25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80

3. Results and discussion

3.1. Effect of the aspirator and feeding rate on maltodextrin/NaCl complexes

A pre-test was used to fix the aspirator rate and the feeding rate at 0.6 m^3/min and 500 mL/h, respectively. At a rate of over 0.6 m^3/min for the aspirator (0.75 m^3/min), the samples in the cyclone went out through the exhaust pipe with a swirling pattern (Fig. 1), and this phenomenon resulted in a low powder yield of less than 10%. The feeding rate also affected the quality of the maltodextrin/NaCl complexes. At a feeding rate of over 500 mL/h, vapor was generated on the walls of the evaporation chamber, and the complexes became stuck on the wall, and as a result, small and fine maltodextrin/NaCl complexes were not produced at over 500 mL/h (Below image). Therefore, the 500 mL/h feeding rate was the optimal maximum speed for this study. Several previous studies had reported that the quality of the powder changed depending on the sample feeding rate. Vehring [27] also explained that the particle sizes of the sample were influenced by the fluid flow (air or liquid), and when the inlet temperature was the same, a high feeding rate (3.0 < 6.0 < 9.0 g/min) caused an increase in the Eudragit RS 30D® particle diameter (12.3 < 16.7 < 24.4 m) during processing. Also, differences in the particle size and morphological properties were observed via SEM [28].

3.2. Effect of the inlet temperature on the size or morphological properties of the maltodextrin/NaCl complexes

The maltodextrin/NaCl solution was spray-dried with various inlet temperatures (130, 140, 150, 160, and 170 °C) at a 100 kPa atomization pressure, 0.6 m^3/min aspirator rate, and 500 mL/h feeding rate. The

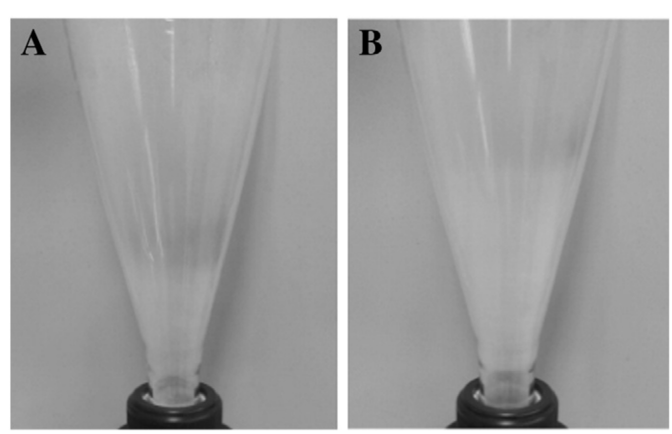

Fig. 1. Effect of the aspirator rate (A: 0.75 m^3/min, B: 0.6 m^3/min) on the distribution of the maltodextrin/NaCl complexes in cyclone.