



## Charging and separation behavior of gluten–starch mixtures assessed with a custom-built electrostatic separator



Jue Wang, Martin de Wit, Remko M. Boom, Maarten A.I. Schutyser\*

Food Process Engineering Group, Wageningen UR, P.O. Box 17, 6700 AA Wageningen, The Netherlands

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### ABSTRACT

Electrostatic separation is a novel and sustainable process for dry separation of food ingredients. To establish guidelines for electrostatic separation, well-defined charging and separation experiments of model mixtures prepared from wheat gluten and starch were carried out. For this a custom-built bench-scale electrostatic separator was developed. Charging behavior of mixtures improved with decreasing particle concentration and increasing gas flow rate, which was similar compared to charging behavior of single materials. However, the charge of mixtures was not simply the sum of the charge of single materials because particle–particle interactions also largely influence the charging. Separation efficiencies for mixtures were found lower than could be expected on the basis of behavior of single materials in the equipment. This was attributed to formation of agglomerates by particles having opposite charge, which was further confirmed by the observation that dispersibility of the mixtures was poorer than for the single materials. Agglomeration of particles during electrostatic separation can be minimized by using high gas flow velocity, low feed dosing and higher field strength.

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### 1. Introduction

Dry fractionation has major advantages compared to wet fractionation of foods into ingredients due to its much lower energy consumption and retention of the native ingredient properties [1,2]. By combining fine milling and dry separation, dry fractionation separates the material into a fraction that is enriched and one that is depleted in a specific target component, such as protein or fiber [3]. Conventionally air classification and sieving are used for the separation step; only recently electrostatic separation has been proposed for dry separation of food materials, although the general principle of electrostatic separation has been applied for decades in mining industries for separation of minerals and purification of coal [4–9], and also for recycling of plastic waste [10–16].

Electrostatic separation based on tribo-electric charging is found effective for separation of small particulates with small differences in conductivity [17,18]. Tribo-electric charging is achieved by entraining particles in a gas flow through a channel, where the particles collide with the walls of the channel and are charged. Subsequently, the charged particles are separated under the influence of an external electric field [19–21], as they are subjected to a

force ( $F_e$ ), which is the product of the charge on the particle ( $q_p$ ) and the electric field strength ( $E$ ). Therefore, the process parameters that influence the charging process and electric field, e.g. particle concentration, gas flow rate, applied voltage and distance between electrodes, influence the effectiveness of separation [4–6,12,22]. While several studies have demonstrated the possibility of using electrostatic separation to fractionate food ingredients, e.g. for the enrichment of aleurone layers and fiber-rich layers in different fractions, respectively, from wheat bran and oat bran [23–30], and for the enrichment of protein from legumes [31], the influence of process parameters such as particle concentration, gas flow and electric field on the electrostatic separation of food ingredients has not been systematically studied.

In our previous study, the tribo-electric charging behavior of a single material was investigated [32]. However, the charging behavior of a mixture is more complex because particle–particle interactions come into play [6,12,33,34]. Therefore, the study reported here aimed at elucidating the role of these interactions, and providing the directions for developing an electrostatic separation process for legumes and cereal. Representative model ingredient mixtures were prepared from purified wheat gluten and starch. Moreover, a custom bench-scale electrostatic separator was constructed, which allowed well-defined charging and separation experiments. The experiments were designed to evaluate the influence of several factors on charging and separation behavior: the

\* Corresponding author.

E-mail address: [maarten.schutyser@wur.nl](mailto:maarten.schutyser@wur.nl) (M.A.I. Schutyser).

composition of mixture, powder dosing rate, gas flow rate, the applied voltage and the distance between two electrodes.

## 2. Materials and methods

### 2.1. Materials

Vital wheat gluten ( $D[4,3] = 67 \mu\text{m}$ ,  $D[3,2] = 17 \mu\text{m}$ ) was obtained from Roquette (France) with the following specifications: moisture 6% (w/w), protein 75–80% (w/w), starch 9% (w/w), cellulose <1% (w/w), fat 7% (w/w) and ash 1% (w/w). Wheat starch ( $D[4,3] = 29 \mu\text{m}$ ,  $D[3,2] = 9 \mu\text{m}$ ) was purchased from Sigma-Aldrich (Germany) with a moisture content of  $10.1 \pm 0.6\%$  (w/w). No further drying of the materials was carried out because the moisture content of both materials is within the range that does not influence the charging process [32,35].

Model mixtures of wheat gluten and starch were prepared by mixing the individual components with a weight ratio of 1:9, 2:8, 3:7, 4:6, 5:5, 6:4, 7:3, 8:2 and 9:1. Because the protein content of wheat gluten is ~80%, the corresponding protein contents of the mixtures are 8%, 16%, 24%, 32%, 40%, 48%, 56%, 64% and 72%, respectively.

### 2.2. Bench-scale electrostatic separator

A vertical bench-scale electrostatic separator was constructed to carry out well-defined charging and separation experiments. It consists of four parts: feeding system, charging slit, separation chamber and collecting chamber (Fig. 1). The feeding system allows independent control of the powder dosing rate and the carrier gas flow rate by introducing the gas flow in a special-designed unit below the outlet of a screw feeder. The screw feeder can accurately dose powder between 0.5 kg/h and 2.5 kg/h. In the transition unit the particles are dispersed by the gas flow and carried downwards to the charging slit. Inside the charging slit, the particles are charged by tribo-electrification due to particle–particle and particle–wall contact. The charging slit is made of aluminum and consists of four parallel channels, all having the same dimension of  $2.5 \text{ mm} \times 3 \text{ mm} \times 220 \text{ mm}$ . After being charged, the particles then are entrained by the gas into the separation chamber, where an electric field is created between two oppositely placed electrodes. One electrode is supplied with a high positive voltage, while the

other one is grounded. The two electrode plates were always kept parallel and only the distance between the electrodes was varied. The particles are deflected based on their charge: positively charged particles to the grounded electrode and negatively charged particles to the positive electrode. At the bottom of the separation chamber two filter bags are mounted to collect the positively charged fraction (PF) and negatively charged fraction (NF), respectively.

### 2.3. Charge measurement

An electrometer (Keithley Model 6215) was connected to the charging slit to measure the impact charge obtained by the slit, and hence of the particles colliding with the slit surface. The measurement and calculation of the specific particle charge, defined as the charge-to-mass ratio, was adapted from a previous study [32]. All measurements were carried out in duplicate.

### 2.4. Separation experiment

Before each separation experiment, the entire system was flushed with dry nitrogen for safety reasons. The run time was adjusted for different powder dosing rates to allow 25 g of powder dosed for each experiment. Five parameters were varied: the gluten-to-starch weight ratio (1:9–9:1); the powder dosing rate (0.5–2.5 kg/h); the gas flow rate (5–30 L/min); the electric field strength (100–250 kV/m, by changing the applied voltage between 10 and 25 kV at a distance of 10 cm between the electrodes) and distance between the electrodes (10–25 cm). Only one parameter was varied at a time while the others were kept constant. From each experiment a positively charged fraction (PF, including the material deposited on the ground electrode and retained in the left collector) and a negatively charged fraction (NF, including the material deposited on the positive electrode and retained in the right collector) were collected, weighed and analyzed on protein content. All the experiments were carried out in duplicate.

Separation behavior was evaluated by determining protein concentrations, relative yield of the fractions and protein separation efficiency. Protein separation efficiency (PSE) is defined as the percentage of protein recovered in the target fraction from the protein in the starting material and is calculated by Eq. (1) [1].

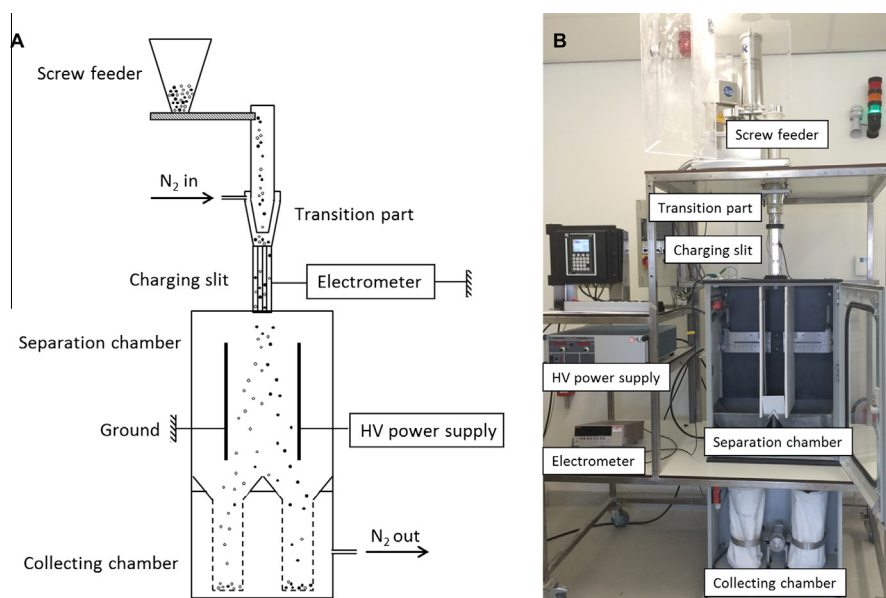


Fig. 1. (A) Schematic drawing and (B) a picture of bench-scale electrostatic separator.

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