Food Research International 62 (2014) 111–120

Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Triboelectric separation of aleurone cell-cluster from wheat bran fragments in nonuniform electric field

Zhongwei Chen [b], Li Wang [b], Ren Wang [b], Yongfu Li [b], Zhengxing Chen [a,b,*]

[a] State Key Laboratory of Food Science and Technology, Jiangnan University, Lihu Road 1800, 214122 Wuxi, Jiangsu Province, PR China
[b] National Engineering Laboratory for Cereal Fermentation Technology, School of Food Science and Technology, Jiangnan University, Lihu Road 1800, 214122 Wuxi, Jiangsu Province, PR China

ARTICLE INFO

Article history:
Received 18 December 2013
Accepted 23 February 2014
Available online 3 March 2014

Keywords:
Aleurone cell cluster
Tribocharging
Nonuniform electric field
Wheat bran
Outer pericarp
Particle size

ABSTRACT

Nonuniform electric field (NUEF) was designed to separate aleurone cell-cluster from wheat bran fragments after tribocharging in a polytetrafluoroethylene tube. After triboelectric separation (TS), the ultrastructure, composition and particle size distribution of the bran fragments were studied. The results showed that, the positive-NUEF had a higher efficiency than the negative-NUEF for the enrichment of aleurone cell-cluster. After the first step of TS in positive-NUEF, about 1.5-time more aleurone cell clusters and 1.3-time more testa particles were deflected to the positive electrodes, while the outer pericarp fragments were enriched in the middle fraction. No obvious difference was found between the particle sizes of the electrode-fraction and middle-fraction, suggesting that the difference in particle size was not the main reason for the charging diversity. After two steps of TS in positive-NUEF, the proportion of aleurone cells increased from 51% to 78% with a total yield of 42%, indicating that the nonuniform electric field was effective for the enrichment of aleurone particles.

1. Introduction

Wheat bran, which is composed of several adhesive tissues, is rich in nutritional compounds including dietary fiber, antioxidant and micronutrient. In wheat bran, the aleurone layer makes up 45–50% of the bran tissues and is composed of thick cell walls enclosing intracellular compounds (Buri, Von Reding, & Gavin, 2004). Lots of studies suggest that the wheat aleurone layer contains the main nutritional ingredients of wheat bran, including 29% β-glucans and 65% relatively linear arabinoxylan in cell walls, and high amounts of phytate, protein, B vitamins and 40%–60% of the total mineral in its intracellular contents. (Bill, 2010; Fincher & Stone, 1986; Pomeranz, 1988; Rhodes, Sadek, & Stone, 2002). Due to its nutritional enrichment, wheat aleurone could be separated into purified fraction, and then be used as ingredients for human food or a starting material for extracting nutritional compounds. However, at present, wheat aleurone layer is usually adhered to other bran tissues and used as a low-value ingredient in animal feed or in fermentation industry due to the lack of separation processes.

Some wet and dry processes have been developed to isolate the aleurone layer from wheat bran (Brouns, Hemery, Price, & Anson, 2012). However, the wet process would lead to the loss of nutritional compounds in the aleurone layer, such as minerals and B vitamins. Meanwhile, the drying of the products in the wet process requires much energy and needs the effluent treatment. Unlike wet fractionation method, dry processes require no chemical pre-treatment and effluent treatment, but only physical/mechanical processes (Gupta, Gidaspow, & Wasan, 1993; Hemery, Rouau, Lullien-Pellerin, Barron, & Abecassis, 2007). Furthermore, dry process mainly focuses on the functionality of phytochemical rather than on the purity (Schutyser & van der Goot, 2011). Thus, it would be beneficial for the retaining of the copious nutritional compounds in wheat aleurone. In the dry process of wheat aleurone separation, dissociation of the aleurone layer from wheat bran is essential. Based on the different mechanical properties of bran tissues, roller milling, hammer milling and centrifugal impact milling can be employed to detach the aleurone layer from wheat bran as the medium particle successfully (Bohm, Bogoni, Behrens, & Otto, 2003; Chen et al., 2013; Stone & Minifle, 1988). But after milling, lots of aleurone cells were broken and dispersed into fine powder, from which the aleurone was difficult to be separated by conventional dry methods, such as air classification and sieving. Meanwhile, the median bran particles (100 μm to 200 μm) contained no more than 45%–50% aleurone layer, and the production of aleurone-rich fraction with high purity is infeasible by using air classification and sieving, due to the tiny difference of bran fragments in size and density after grinding (Hemery et al., 2011).

Abbreviations: TS, triboelectric separation; NUEF, nonuniform electric field; PTFE, polytetrafluoroethylene; CIM, centrifugal impact milling; D_{50}, median particle diameter; DHD, dehydrodimers of ferulic acid; FAt, 4-O-8′,5′-5″dehydrotriferulic acid; ARs, alkylresorcinols; p-CA, para-coumaric acid.

* Corresponding author at: State Key Laboratory of Food Science and Technology, Jiangnan University, Lihu Road 1800, 214122 Wuxi, Jiangsu Province, PR China. Tel./fax: +86 510 85197856.
E-mail address: zxchen_2008@126.com (Z. Chen).

http://dx.doi.org/10.1016/j.foodres.2014.02.043
0963-9969/

Recently, triboelectric separation (TS) based on the different electrostatic properties of the bran tissues, has been developed to obtain aleurone-rich fraction (Brouns et al., 2012). In general, TS involves the two steps including the tribocharging and electric separation in an electric field. During the tribocharging process, the bran particles acquire charges conveniently by impacting with each other or with tribocharging device. After that, the bran particles can be induced by the electric field force, and are deflected to the different place. Triboelectric separation was used firstly by Stone and Minifle (1988) to isolate aleurone particles from wheat bran mixtures. In their process, the blends of aleurone and testa-pericarp particles, which were obtained by hammer milling, were charged in an elutriator column and separated in the uniform electric field (+10,000 V). According to the patent, almost pure aleurone fraction (purity of 95%) could be obtained with a yield of 10%. In the TS processes of aleurone layer introduced by Bühler AG (Bohm & Kratzer, 2005, 2008), the medium-scale bran fragments were charged by using either a disk-shaped rotor equipment, or in a curved charging pipe (stainless steel). After tribocharging, the aleurone particles were enriched in positive electrode in a uniform electric field. Hemery et al. (2011) also studied the TS of the aleurone cells, but using the fine bran powder (D_{50} = 50 μm) as the starting material. In the process, wheat bran powders were charged in a curved tribo-tube (did not mention the material). They found that the broken aleurone cells (cell walls and cell contents) were enriched at the negative electrode in the uniform electric field. However, no study was carried on the separation of aleurone particles in nonuniform electric field (NUEF), although the NUEF has been widely used in the electrostatic precipitation of fine powder (Mizuno, 2000).

In this study, triboelectric separation of wheat bran fragments was carried out in the nonuniform electric field after tribocharging in the polytetrafluoroethylene (PTFE) tube. The deflected behaviors of aleurone particles in the positive and negative NUEFs were investigated based on the analysis of biochemical composition. TS in positive-NUFE was used to obtain the aleurone-rich fraction using wheat fragments with different particle sizes. Moreover, the particle size distributions of bran fragments obtained by TS were studied. The principle of tribocharging separation was also discussed in order to improve the production of wheat aleurone by TS.

2. Materials and methods

2.1. Materials and chemicals

Wheat bran used in this study was the commercial product supplied by COFCO (China Oil And Foodstuffs Corporation, Beijing, China), and was obtained via a conventional roller milling process. Before triboelectric separation, the tissues (aleurone layer, outer pericarp and intermediate layer) in wheat bran were dissociated using a centrifugal impact milling (CIM) according to the process described by Chen et al. (2013). After grinding, the wheat bran fragments, which passed through 100-mesh grid but was over the 200-mesh grid, were used as the starting material of TS. The starting material was further separated into three fractions ($F_{(100–120)}$, $F_{(120–150)}$, and $F_{(150–200)}$). $F_{(100–120)}$ represents the bran fragments passed through the 100-mesh grid, but did not pass through 120-mesh grid. $F_{(120–150)}$ and $F_{(150–200)}$ are the bran fragments obtained by the similar processes.

Fluorescent brightener 28, phytic acid, para-coumaric acid, 3,4,5-trimethoxycinnamic acid, and olivetol were purchased from Sigma-Aldrich (St. Louis, MO, USA). Ferulic acid, agar, ethanol, trifluoroacetic acid and glutaraldehyde (AR grades) were purchased from Sinopharm (Beijing, China). Methanol and acetonitrile were all high performance liquid chromatography (HPLC) grades, and the ultrapure water was produced by Direct-Q3 UV Water Purification System (Millipore Corporation, Billerica, MA, USA).

2.2. Triboelectric separation of wheat bran fragments

A lab-scale triboelectric separation system was used for the production of aleurone-rich and outer pericarp rich fractions from bran fragments. As shown in Fig. 1, the system includes a feeder (a glass funnel), a tribo-tube made of PTFE, an electrostatic separation chamber and a high-voltage power supply. In the electrostatic separation chamber, the nonuniform electric field was built by two high-voltage electrodes and a grounded electrode, to separate the charged bran particles. The voltage of the high power supply was set at −45,000 V or +45,000 V. During the TS, the bran fragments were fed into the glass funnel at a rate of 50 g/min, and were transported by the air flow (3.0 ± 0.05 m/s) into the tribocharging device. The bran fragments were charged by the particle–wall and particle–particle collisions, and then were sorted by the electrostatic force in the electric field. At the bottom of separation chamber, three vessels were used to recover the bran fractions. The bran fragments between the electrodes were collected in the middle vessel, and the bran fragments on the electrodes were collected in the other two vessels. After the first step of TS, the electrode-fraction was used as the starting material for the second step of TS. The temperature and humidity of air flow were controlled at 27 ± 2 °C and 37 ± 2%, respectively.

2.3. Chemical analyses

Before the chemical analysis, all the bran samples were ground using a planetary mill (QM-QX04, Tianchuang powder technology Co., Ltd., Changsha, China) until the powder passed through the 0.15 mm grid.

The content of starch was determined according to the AACC approved method 76-13 (AACC, 2000). Phytic acid, which was a biochemical marker of wheat aleurone cell content, was measured at 500 nm from acidic extracts according to the colorimetric method

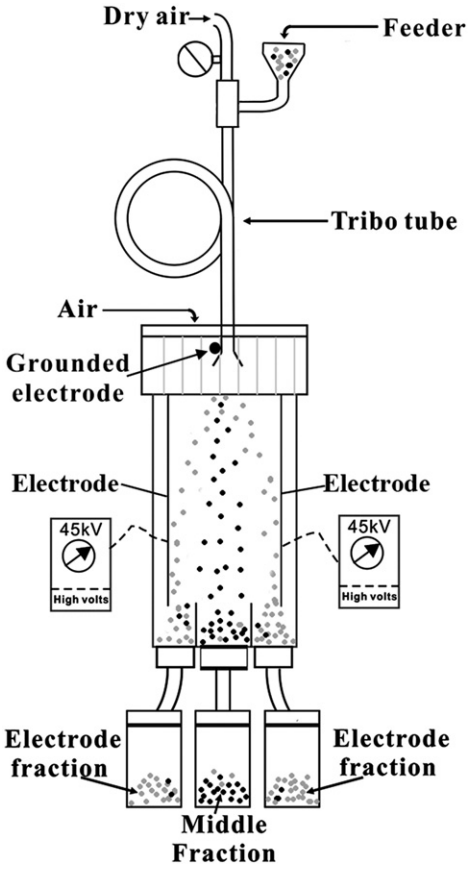

Fig. 1. Experimental set-up of triboelectric separation in nonuniform electric field.