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The Separation of Free Bran by Using Electricity-Assisted Electrostatic Field System

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ABSTRACT

In this study, it was to identify a method for separating the free bulgur bran from the fine bulgur during the production of bulgur. This was attempted by creating an electrostatic field using a PVC surface. It was observed that the issue of free bran, which adversely affects the packaged products visually, was effectively solved by this method. In contrast to conventional techniques, an alternative methodology was employed which utilizing a device comprising a folded PVC surface (folded curved channel). The configuration of the experimental apparatus was developed with dimensions of 4, 5 and 6 cm in width, 20, 40 and 60 cm in length, and angles of 30, 35 and 40 degrees, respectively. At the end of the PVC surface, plates were placed to create an electric field. In order to create the electric field, one of the plates was charged with a positive and the other with a negative charge. The distance between the plates was varied according to the width of the tunnel. The expected results were obtained in the layered PVC system. Consequently, a fine bulgur mixture consisting of 5 g of bran per 1000 g of bulgur was introduced into the experimental system at a flow rate of 0.89 g/s. This resulted in a notable reduction in the free bran content, which decreased from 5 g to approximately 2 g.

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Introduction

Bulgur is a foodstuff derived from the whole grain of the durum wheat (Triticum durum) plant. It is manufactured through a process involving the following steps: cooking, drying, debranning, milling, and size classification (Michel & Bayram, 2024). Bulgur is a nutritious and healthy product with a long shelf life, made from durum wheat without any additives (Yılmaz, 2020). Traditional food in Turkey, the Balkans and the Middle East, bulgur is becoming increasingly popular due to its additive-free, low-cost, easy production and storage, a wide range of uses and delicious taste (Tekin et al., 2021). Bulgur is known for its versatility in various dishes and is available in different forms such as fine, medium coarse, coarse, and extra coarse bulgur (Göksu et al., 2022).

Bulgur bran is the outer layer of the bulgur kernel, which is rich in dietary fiber, vitamins, minerals, and phytochemicals. It is considered a valuable component of the bulgur grain, offering a range of health benefits and nutritional properties (Yağcı et al., 2022).

Although bulgur bran is a nutritionally rich foodstuff, it is not a preferred food item for the end consumer. The inability of traditional methods to separate bulgur bran results in the product becoming adherent to the internal surface of the packaging, thereby giving the impression of inferior quality.

Electrostatic separation is a methodology employed for the differentiation of particulate matter on the basis of its electrical properties and characteristics of triboelectric charging (Higashiyama & Asano, 1998). Same or very similar densities can be separated by electrostatic separation (Rybarczyk et al., 2020). Electrostatic separation is used in many different fields such as recycling, waste and geology (Bebin et al., 2014). The application of an electrostatic field for the isolation of bran from bulgur may prove advantageous in enhancing the efficiency and effectiveness of the process. This approach provides a distinctive method for the effective separation of both components, which can be challenging to achieve through conventional techniques (Kayıran & Bayram, 2024). A fundamental aspect to be taken into account is the specific composition of the particles of bran and bulgur that are subjected to the separation process. Additionally, the dimensions and configuration of the particulates may impact the separation procedure, as particles with disparate properties may exhibit varying responses to the electrostatic field. (Zhu et al., 2023). Polyvinyl chloride (PVC) is used for the electrostatic separation process.

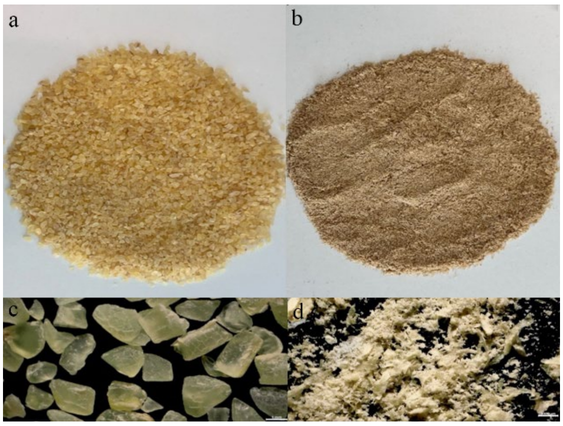

Figure 1. Images of (a) fine bulgur, (b) bran [3× images], (c) microscope images of fine bulgur and (d) bran [magnification 300 dpi, scale 1000 micrometer

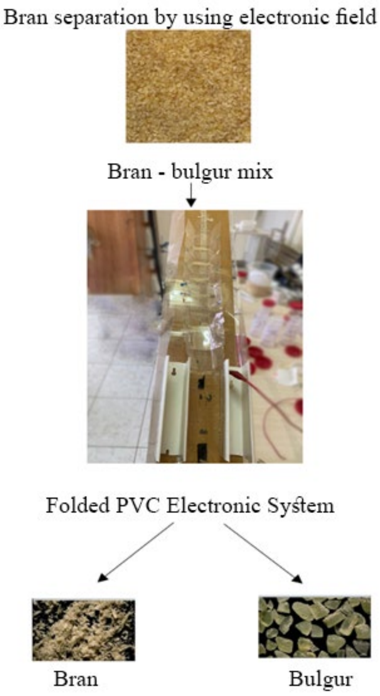

Figure 2. Schematic diagram of the separation system.

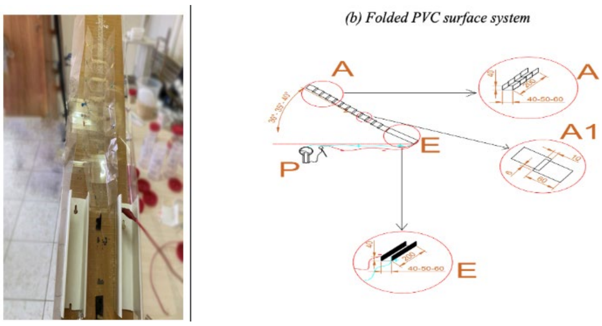

Figure 3. Folded PVC surface systems.

The electrostatic field system generated using electricity is an effective technique that offers a solution for the separation of bulgur and free bran, which are difficult to separate by conventional methods. However, it is important to note that the success of this method can vary depending on several factors.

The objective of this study is to examine the use of a PVC surface electrostatic system and electric field for the separation of bran from bulgur (Figure 2 and Figure 3). Also to determine the effectiveness of PVC surface (folded inclined channel) in creating electrostatic field and electric field effectiveness.

Materials and Methods

Sample Preparation

Fine bulgur and bulgur bran samples provided by a local food company (Tiryaki Agro Gıda San. ve Tic. A.Ş., Gaziantep, Turkey, 2021) were used in this study. (Figure 1). Fine (köftelik) bulgur was processed according to Antep type method (Yousif et al., 2018). Moisture, protein and ash contents and colours of the bulgur and bran samples were determined. Bulgur and bran were sieved using 0.5 mm and 2 mm sieves respectively. The samples were prepared in accordance with industry data to contain 5 g/1000 g bulgur bran.

Determination of Colour

The colour values (L^*, a^*, b^* and YI) were determined by means of a Hunter Lab Colourimeter (Colourflex, USA). The Hunter scale quantifies the perceived lightness (brightness) of a given colour, with L representing a value ranging from white to black. The a-value indicates the degree of redness, while the b-value denotes the intensity of yellowness (positive values), greyness (zero values) and blueness (negative values). The YI, or yellowness index, is a measure of the relative intensity of yellow tones in a given colour.

Determination of Protein Content

The protein content was determined using the Kjeldahl method (AOAC 1990), expressed as a percentage (%), a ratio of grams to grams (g/g), and as a dry basis. The conversion factor was established as 6.25.

Determination of Ash Content

Determination of ash content was performed according to AOAC (1990) methods.

Electrostatic Separation Experiment with Electric Field

The system was developed with a surface composed of folded PVC to facilitate the creation of electrostatic and electric field effects, as demonstrated in (Figure 3). Fine bulgur (containing 5 g/1000 g bulgur bran) was passed through the PVC surface at varying lengths (20, 40 and 60 cm), angles (30, 35 and 40°) and widths (4, 5 and 6 cm), respectively.

Following a series of controlled experiments in a laboratory setting, it was established that both bulgur and bulgur bran display positive triboelectric characteristics when subjected to triboelectric testing. In order to distinguish between the various materials in question, an electrostatic field was generated utilizing the negative triboelectric characteristics inherent to PVC, as a consequence of friction.

PVC is a polymer that is employed in a multitude of applications, including cables, thermoplastics, and polymerized vinyl chloride products (Thabet, 2024). The material is produced through the polymerization of vinyl chloride and is renowned for its versatility and durability. Due to its cost-effectiveness and resistance to chemicals, weathering and impact, PVC is one of the most commonly used materials (Andrady & Neal, 2009).

PVC is susceptible to the accumulation of negatively charged particles due to the triboelectric principle, which is defined as the movement of an electric charge by the transfer of electrons between materials in frictional contact (Miura et al., 2014).

It was observed that how much bulgur bran could be separated by passing the bulgur through the devices prepared from PVC material and the electric field with a certain mass flow rate.

Figure 3 shows that the system design of folded PVC surfaces and electric field. The folded system was prepared with PVC assemblies with the widths of 4, 5 and 6 cm and lengths of 20, 40 and 60 cm, respectively. Different angles were designed therefore the angle of the system was 30, 35 and 40°. Each layer in Figure 3, A1 overlaps by 1 cm with a distance between overlaps of 0.6 cm (four layers make up a length of 20 cm with a channel depth of 4 cm). Plates are placed to create an electric field where the PVC surface ends. To create the electric field, one of the plates was charged with a positive and the other with a negative charge. The distance between the plates was varied as the tunnel distances (4, 5 and 6 cm). The electric field was calculated according to the following formulation (Eq.1).

$$E = \frac{V}{d} \quad (1)$$

In this formula, E (V/m) is the electric field, V (V) is the potential difference between the two plates and d (m) is the distance between the two plates. (Fitzpatrick, 2010). According to this formula, the electric field for 4, 5 and 6 cm width is 5500 kv, 4400 kv and 3666 kv respectively.

Van de Graaff generator was also used as the power source for the electric field. The generator works on the principle of generating high voltages from a current-limited source (Lee et al., 2017). This generator consists of an isolating belt driven by an electric motor and stretched between two rollers (Electrostatic Accelerator, 2014). The maximum voltage capacity of the generator depends on the diameter of the generator sphere. The voltage collected by the generator can be calculated approximately over the maximum value. For a 25 cm diameter sphere, the theoretical voltage collected by the generator is based on 220kv (Ege et. al., 2014). In addition, in order to accumulate sufficient potential voltage, the generator waited for 5 minutes after the generator started and then the bulgur flow was realized.

Characterization by Infrared Spectroscopy (FT-IR)

In order to ascertain the impact of groupings within the chemical composition on the electrostatic field, Fourier Transmitter Infrared Spectroscopy (FT-IR) was employed, utilizing a PerkinElmer Spectrum 100 FT-IR spectrometer (PerkinElmer Inc., Waltham, MA, USA). This was conducted on a range of samples, including bran, fine bulgur and bulgur-bran blends (5 g bran / 1000 g bulgur). The mid-infrared spectra were obtained using 4 cm^{-1} resolution and 4 scans with the Spectrum 10 STD software (PerkinElmer Inc., Waltham, MA, USA). This allowed for the collection of spectra in the range of 4000-650 cm^{-1}. The transmittance spectra of each individual sample were obtained on four separate occasions, with the ground sample positioned at the center of the diamond crystal on each occasion.

Statistical Analysis

The effect of ΔX, L and α on the system was assessed using a standardized analysis of variance (ANOVA). Correlations that were statistically significant were identified according to the Pearson coefficient, with the level of significance defined as $P \leq 0.05$ and $P \leq 0.01$. All statistical analyses were carried out using the SPSS software package (SPSS Inc., Chicago, IL, USA). In order to ensure accuracy and reliability, the measurements were duplicated, and the experiments were replicated.

Result and Discussion

The bulgur sample exhibited a moisture content of 10.5% on a dry basis (d.b.), whereas the bran sample showed a moisture content of 10% (d.b.). The protein content of the bulgur was found to be 10.26% dry basis (d.b.), while the protein content of the bran was determined to be 14.22% (d.b.). The ash content of the bulgur was found to be 0.89% (d.b.), while the bran exhibited an ash content of 3.80% (d.b.). In order to gain an understanding of the efficiency of the system, it is necessary to consider both the changes in the amount of ash and the gains in bran. Simultaneously, the colour values, which are fundamental in defining the quality of bulgur, were as follows: The L^*, a^*, b^*, and YI values for the bran were 64.18, 6.34, 38.39, and 81.07, respectively. For the bulgur, the corresponding values were 70.62, 4.86, 25.99, and 57.56. The samples were passed through a system with a folded PVC surface. The bulgur-bran mixture displaying the specified characteristics was subjected to the system, and the efficacy of the system was evaluated based on the results of the gained bran (GB), with a particular focus on the measurement of the quantity of bran separated by the electrostatic field and the ash analysis results. Gained bran (GB) is the amount of bran removed from the system with the help of PVC surface.

The present study employed PVC with extreme negative triboelectricity in the bulgur production industry, with the objective of investigating both the influence of different parameters, including PVC surface width (ΔX), length (L) and angle (α), and the impact of these variables on bran separation.

The data demonstrated a notable positive correlation with ash content and gain value in the folded PVC with an electric field system. The impact of key design parameters, specifically the width (ΔX), length (L) and channel angle (α), of a folded PVC with an electric field system was analysed.

A significant difference ($P \leq 0.05$) was observed between the quantities of bran gained with respect to the width (ΔX) of the folded PVC in the presence of the electric field system. The amount of bran gained in PVC samples of 4 cm, 5 cm, and 6 cm width was 0.10 ± 0.02 g, 0.11 ± 0.03 g, and 0.07 ± 0.01 g, respectively. Upon examination of the differences between the groups, it was determined that the amount of bran gained in the 5 cm width PVC samples was higher than in the other widths.

The results demonstrated that there were no significant differences in the channel angle (α), (ΔX* α) and (L* α) when the length (L) was taken into account. A statistically significant difference ($P \leq 0.05$) was observed with respect to the quantities of gained bran in accordance with the (ΔX* L* α) variable. The greatest degree of bran separation was observed in tests conducted with tunnel widths of 5 cm, lengths of 40 cm, and system angle of 30^{o} degree.

The results were additionally subjected to correlation analysis using Pearson's correlation coefficient. In the folded system, a significant negative correlation (-0.482) between ΔX and GB was observed and positive correlation (0.490) between ash content and ΔX.

The outcomes derived from Duncan's multiple test analysis, as illustrated in (Table 1), indicated that the width, length and angle (α) of the channel were instrumental in facilitating the effective separation of the bran from the bulgur.

Table 1. The results of the folded electrostatic system using an electric field.

Parameters ΔX (cm)	L (cm)	A (°)	Elestrostatic systems with electric field Folded PVC system Gained bran (g)	Ash content (%, g/g, d.b.)
4	20	30	0.08±0.00 ^{a,b,c,d}	3.49±0.09 ^{e,f,g,h}
		35	0.07±0.03 ^{a,b,c}	3.65±0.13 ^{f,g,h}
		40	0.10±0.01 ^{d,e,f,g}	3.00±0.00 ^{c,d}
	40	30	0.11±0.13 ^{d,e,f,g}	2.53±0.22 ^{a,b}
		35	0.09±0.01 ^{a,b,c,d,e}	3.35±0.39 ^{d,e,f,g}
		40	0.10±0.02 ^{d,e,f,g}	3.15±0.13 ^{c,d,e}
	60	30	0.12±0.01 ^{e,f,g}	2.35±0.10 ^{a,b}
		35	0.11±0.01 ^{d,e,f,g}	2.75±0.17 ^{a,b,c}
		40	0.83±0.02 ^{a,b,c,d}	3.43±0.13 ^{d,e,f,g}
5	20	30	0.11±0.01 ^{d,e,f,g}	2.78±0.19 ^{b,c}
		35	0.12±0.01 ^{f,g}	2.30±0.18 ^{a}
		40	0.10±0.01 ^{c,d,e,f,g}	2.30±0.12 ^{a}
	40	30	0.13±0.02 ^{g}	2.80±0.71 ^{b,c}
		35	0.11±0.01 ^{e,f,g}	2.50±0.16 ^{a,b}
		40	0.11±0.01 ^{d,e,f,g}	2.78±0.10 ^{b,c}
	60	30	0.08±0.06 ^{a,b,c,d}	3.53±0.59 ^{e,f,g,h}
		35	0.10±0.02 ^{c,d,e,f,g}	3.18±0.45 ^{c,d,e}
		40	0.10±0.02 ^{b,c,d,e,f}	3.25±0.13 ^{d,e,f}
6	20	30	0.06±0.00 ^{a}	3.80±0.14 ^{g,h}
		35	0.07±0.01 ^{a}	3.75±0.19 ^{g,h}
		40	0.07±0.00 ^{a,b}	3.70±0.18 ^{f,g,h}
	40	30	0.07±0.00 ^{a,b}	3.73±0.15 ^{g,h}
		35	0.07±0.01 ^{a,b,c}	3.90±0.75 ^{h}
		40	0.06±0.00 ^{a}	3.80±0.08 ^{g,h}
	60	30	0.06±0.01 ^{a}	3.78±0.10 ^{g,h}
		35	0.07±0.01 ^{a}	3.75±0.06 ^{g,h}
		40	0.07±0.01 ^{a}	3.78±0.10 ^{g,h}

ΔX: width of channel (cm), L: length of channel (cm), α: angle of channel (°); a, b, c etc. :Homogeneous groups were shown significant differences between the values in the same column.

Table 2. Pearson correlation of folded PVC system

		ΔX	L	α	GB	ASH%
ΔX	Pearson Correlation	1				
	Sig. (2-tailed)					
	N	108				
L	Pearson Correlation	0.000	1			
	Sig. (2-tailed)	1.000				
	N	108	108			
α	Pearson Correlation	0.000	0.000	1		
	Sig. (2-tailed)	1.000	1.000			
	N	108	108	108		
GB	Pearson Correlation	-0.482**	-0.005	-0.042	1	
	Sig. (2-tailed)	0.000	0.955	0.668		
	N	108	108	108	108	
ASH%	Pearson Correlation	0.490**	0.079	0.032	-0.647**	1
	Sig. (2-tailed)	0.000	0.417	0.741	0.000	
	N	108	108	108	108	108

**: Correlation is significant at the 0.01 level (2-tailed); GB: Gained bran (g), ΔX: width of channel (cm), L: length of channel (cm), α: angle of channel (°), Ash%: Ash content

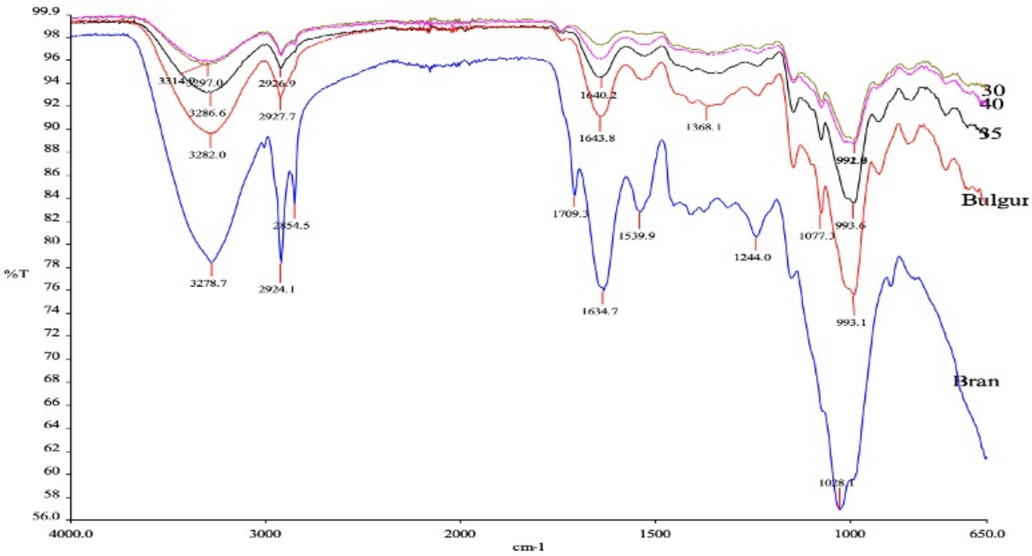

Figure 4. F-TIR Spectra of Bulgur, bran and angle of the system were shown. F-TIR Spectra of folded PVC with electric field system, ΔX 5 cm, L 40 cm.

It was found that the optimal method for separating the bran from the bulgur was to utilize a middle channel width and length, along with the lowest channel angle. Therefore, a 30° system angle, 5cm width and 40 cm length can be selected for operational conditions in industrial applications. In parallel with the bran values recovered, the ash content generally decreased.

The structure of bulgur–bran mixtures, bulgur and bran were studied using Fourier transform infrared (FT-IR) spectroscopy following their passage through different angle assemblies. Bulgur, bran and angle of the system were shown in Figure 4. The peaks observed at around 3278 cm^{-1} are associated with the O-H where the region of hydrogen bonds is subject to stretching, which are formed between aliphatic and aromatic groups of alcohol and water. It can be inferred that the peak at 2925 cm^{-1} is indicative of a C-H linkage, this is linked to an aldehyde compound. The observed peaks have been identified as originating from structures comprising cellulose and starch (Berthomieu et al. 2009). A peak at 1635 cm^{-1} was identified, which corresponded to amide I. It may be proposed that the peaks observed at 1365 and 1148 cm^{-1} can be associated with the formation of a C-H bond and may be indicative of structural characteristics associated with cellulose. Furthermore, the observation of peaks at 1077 cm^{-1} provides evidence of alterations in the structure of several polysaccharides. The presence of a C-OH peak at 994 cm^{-1} is indicative of the occurrence of C-OH bending. (Amir et al., 2013; Bledzki et al., 2010). The FTIR spectroscopy data indicate that no significant alterations were observed in the bran and bulgur samples during the process of separation using PVC surfaces. This evidence suggests that the chemical composition of the two samples remains relatively similar. The obtained FTIR spectra demonstrate that there is no significant structural change during the separation of bran from bulgur. Consequently, the FTIR spectra indicate that bran separation does not result in any alteration to the structure of bulgur.

Application of the Systems in Industry

Since bulgur production is constantly evolving, it is necessary to re-analyze all production processes. Although some conventional separation techniques are utilized in the separation of bulgur bran following the milling stage in the production of bulgur, the separation of the two components is not complete. Unseparated bran continues to present problems in the sector to date. Its adhesion to the inner surface of packaging results in fine bulgur appearing different (of lower quality) to consumers. This study proposes an improvement process designed to solve these problems. The system described in the study can be integrated into the pre-packaging process.

Prior to packaging, separation of fine bulgur from bran is possible using a PVC surface that generates electrons through frictional forces. Following a specific quantity of bulgur transfer, the surface of the system may become entirely covered in bran. To ensure the optimal functionality of the system, the PVC surface necessitates regular cleaning through the utilization of a mobile brush and/or negative pneumatics (vacuum).

Conclusion

The outcomes of this study have significant consequences for the sector of the food industry, as they illustrate the potential of a novel approach to the processing of cereal grains, including the production of bulgur. Moreover, the implementation of an effective and eco-friendly approach to bran separation will facilitate the development of more sustainable production methodologies, enhance the quality of the final product and improve its nutritional profile.

Consequently, the utilization of an electrostatic field and electric field represents a promising methodology that presents a novel and efficacious solution to the issue of separating the bran bulgur component. In order to ensure a successful separation, it is essential to give due consideration to a range of factors, including those concerning the characteristics of the particles, the strength of the electrostatic field and electric field, and the precise configuration. Through a process of systematic trial and error, this method can be refined to achieve more effective distinction and more favorable outcomes. Subsequent research and experimentation may be conducted in this field with the objective of developing new and improved food processing techniques, resulting in the production of nutritionally enhanced and improved food products of a higher quality. The results of this study will prove invaluable in analyzing the impact of processing cereal products via electrostatic and electric fields, and in optimizing production processes. Furthermore, the findings of this study contribute to the academic knowledge base by empirically demonstrating the utilization of electrostatic and electric fields in food separation, as well as operational techniques for industry to enhance the quality of cereal products.

Declarations

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Conflict of Interest

There is no conflict of interest.

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