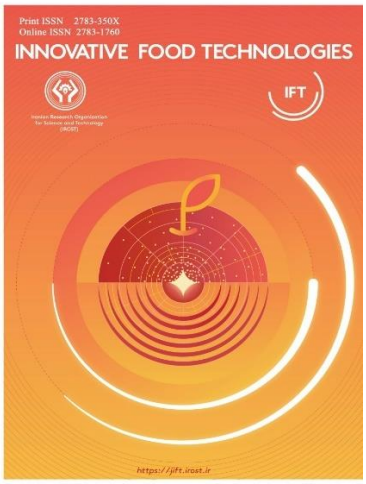
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Effect of Hydrothermally Treated Wheat Bran on Dough Pore Structure Assessed by X-ray CT

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Abstract

The effects of wheat bran type and inclusion level on dough pore structure during fermentation were investigated using X-ray computed tomography (CT). Five dough formulations containing raw or hydrothermally treated bran at different inclusion levels were analyzed after 60 and 120 min of fermentation. Surface porosity, mean pore area and mean pore diameter were quantified. Dough containing 15% raw bran exhibited the highest values of these parameters at 60 min and the second-highest surface porosity and mean pore area at 120 min, whereas 9% hydrothermal bran showed the lowest values for all three parameters at both fermentation times, with a more homogeneous pore structure visually observed. Increasing the hydrothermal bran level to 15% resulted in less favorable pore development, which was partially improved by increasing sugar and improver levels. Overall, hydrothermal treatment improved the pore characteristics of bran-containing dough at an appropriate inclusion level, with 9% hydrothermal bran showing the most favorable structural characteristics among the formulations investigated.

Key words: X-ray computed tomography; Wheat Bran; Dough; Hydrothermal treatment.

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1. Introduction

Porosity is a macroscopic descriptor of pore structure that reflects the underlying microscopic architecture. This architecture can be characterized by parameters such as specific surface area, mean pore size, pore size distribution (based on volume, surface area or pore number), pore shape, pore wall thickness and pore interconnectivity (Gueven and Hicsasmaz, 2013). Food products such as baked, extruded, puffed, dried and frozen foods inherently possess a porous microstructure that determines their characteristic texture, which is commonly quantified in terms of physical properties such as tensile strength, compressive strength and stiffness (Włodarczyk-Stasiak and Jamroz, 2009). In recent years, X-ray computed tomography (CT) has been widely adopted for investigating the microstructure of food systems. X-ray CT is a non-invasive imaging technique capable of producing high-quality three-dimensional images, enabling detailed characterization of internal structural features (Withers, 2021). Accordingly, this technique is particularly well suited for examining porous matrices due to the contrast in X-ray attenuation between voids and solid matter (Contardo, 2020). Previous X-ray CT studies on bread have mainly focused on visualizing and quantifying its porous structure, including parameters such as cell wall thickness, void fraction, bubble growth and pore size distribution (Chaple, 2023; Olakanmi, 2023). However, limited information is available on the evolution of dough pore morphology during fermentation when different types and levels of wheat bran are incorporated. The objective of this study was to use X-ray computed tomography to investigate how bran type and formulation affect surface porosity and pore morphology of dough during fermentation.

2. Materials and method

2.1 Material

The flour used in this study was a Chamran variety wheat flour (extraction rate: 56%), supplied by the Agricultural Research Center of Khuzestan Province, Iran. Raw food-grade wheat bran was obtained from the Harand flour factory (Isfahan, Iran) and stored at −18 °C prior to use.

2.2 Hydrothermal treatment

The raw bran was sieved using a 180 µm mesh to obtain a more uniform particle size distribution. For hydrothermal treatment, 300 g of the sieved bran was soaked in an acetate buffer solution (pH 4.8) at 55 °C in an incubator for 1 h, using a buffer-to-bran ratio of 2:1 (v/w). The buffer solution was then replaced and the hydrothermal treatment was continued for an additional 23 h. Finally, the hydrothermally treated bran was dried in an oven at 37 °C and subsequently sieved again using a 180 µm mesh (Mosharraf, 2009).

2.3 Dough preparation

Five dough formulations were prepared: a control without bran, doughs containing 15% raw bran, 9% hydrothermally treated bran, 15% hydrothermally treated bran, and 15% hydrothermally treated bran with increased sugar and improver levels. All formulations contained 2% sugar, 1% salt, 0.5% improver, and 1% yeast, except the latter, which contained 2.5% sugar and 1% improver. It should be noted that hydrothermal treatment reduces the amount of endosperm accompanying the bran significantly, meaning that a purer bran fraction is obtained after hydrothermal treatment. It was found that 300 g of raw bran produced 180 g of hydrothermal bran. This shows a yield of 60% for the hydrothermal treatment. This is the reason for choosing 9% hydrothermally treated bran for comparison with 15% raw bran. This means that with the mentioned percentages (15% raw bran and 9% hydrothermal bran), the amount (by weight) of bran in raw and hydrothermal samples is

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equal, so they can be compared more precisely.

2.4 X-ray CT Imaging

To evaluate surface porosity, pore area and pore diameter of dough using X-ray computed tomography, five dough samples described in section 2.3 were manually prepared. To monitor surface porosity evolution during fermentation, CT scans were performed 60 and 120 min after dough preparation. Imaging was carried out using a Shimadzu single-slice CT scanner (model L140CT, Japan). As shown in Figure 1, the five dough samples were placed in rigid containers and positioned vertically beneath the scanner. The imaging parameters were set to an X-ray tube voltage of 120 kV, a tube current of 110 mA and a slice thickness of 10 mm. Between scanning intervals, the samples were kept sealed and maintained in a warm environment to allow fermentation to proceed.

2.5 Image analysis

CT scan image analysis was performed using a custom-developed image processing workflow implemented in MATLAB. Image preprocessing included adaptive histogram equalization to improve contrast uniformity, followed by region-of-interest (ROI) definition to isolate the dough area from the background. The images were then converted to binary format using threshold-based segmentation, enabling identification of pore structures within the dough matrix. Geometric properties of individual pores, including pore area and equivalent pore diameter, were extracted using region-based image analysis. Surface porosity was calculated as the ratio of total pore area to the corresponding ROI area, and mean values were calculated for each dough formulation.

3. results and discussion

The reported porosity represents surface porosity derived from 2D CT slices; thus, limited vertical expansion of dough samples results in smaller cross-sectional areas and consequently higher surface porosity values. As shown in Table 1, the dough containing 15% raw bran exhibited the highest surface porosity, mean pore area and mean pore diameter after 60 min of fermentation, as well as the highest mean pore diameter after 120 min. At 120 min, this formulation ranked second in terms of surface porosity and mean pore area, with the dough containing 15% hydrothermally treated bran showing higher values. The dough containing 15% raw bran exhibited a more compact solid phase and limited dough expansion. Under these conditions, pores were concentrated within a smaller surface area, leading to increased surface porosity values. The undesirable effects observed in dough containing raw wheat bran are mainly attributed to competition with gluten for water, leading to moisture redistribution and partial gluten dehydration (Li, 2023; Yan, 2022), as well as physical disruption of gas cells and the gluten network during mixing (Li, 2023). In addition, dietary fibers dilute gluten proteins, weakening network integrity and dough extensibility (Han, 2019), while bran components such as glutathione can reduce disulfide bonds in gluten, further impairing dough viscoelasticity (Li, 2012). These detrimental effects are markedly reduced in hydrothermally treated bran.

In dough formulated with 9% hydrothermally treated bran, the lowest values for all three parameters were observed. Accordingly, the low surface porosity observed in the dough containing 9% hydrothermal bran after 120 min of fermentation can be attributed to its greater expansion during fermentation, resulting in a larger cross-sectional area and the formation of smaller and more uniformly distributed pores. At a 15% inclusion level of hydrothermally treated bran, increased competition between hydrothermal bran and gluten for water uptake may limit gluten hydration and network development (De

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Bondt, 2021). This may be attributed to the relatively high amount of hydrothermally treated bran incorporated into the dough, which resulted in reduced fermentation and less expansion compared with the other dough samples. Under these conditions, the beneficial effects of hydrothermally treated bran on dough performance may be diminished. The addition of an excess amount of sugar and improver to the dough containing 15% hydrothermally treated bran resulted in mean pore area and diameter values comparable to those of dough containing 15% raw bran. This indicates a less compact solid phase and more effective dough expansion, suggesting that the added sugar and improver partially mitigated the restrictive effect of the high bran content. However, these values remained less favorable than those observed for the dough containing 9% hydrothermally treated bran. Among the hydrothermally treated formulations investigated in this study, the 9% hydrothermal bran formulation showed the most favorable pore characteristics.

In our previous macroscopic fermentation study (Tavanai, 2025), the dough containing 9% hydrothermally treated bran exhibited one of the highest fermentation heights and the best structural stability among the bran-containing samples, whereas the other dough samples showed a greater reduction in height and lower stability after fermentation. These observations are consistent with the present CT-based analysis, in which dough containing 9% hydrothermally treated bran exhibited lower surface porosity and finer pore structures and was the closest to the control sample. In contrast, the other samples showed higher surface porosity, which was associated with limited dough expansion.

4. Conclusion

X-ray computed tomography was shown to be a useful non-destructive technique for characterizing pore structure development in doughs containing different types and levels of wheat bran. Hydrothermally treated bran, when incorporated at an appropriate inclusion level, promoted dough expansion and resulted in lower surface porosity and finer, more uniformly distributed pores. In contrast, dough formulated with 15% raw bran exhibited limited expansion and higher surface porosity, reflecting a more compact dough structure and less favorable pore characteristics. The combined CT-based observations and previous macroscopic fermentation findings indicate that hydrothermal treatment can improve the functional performance of wheat bran and support dough structural development when applied at an appropriate inclusion level, whereas excessive bran incorporation may limit these benefits due to increased competition for water and disruption of gluten network development.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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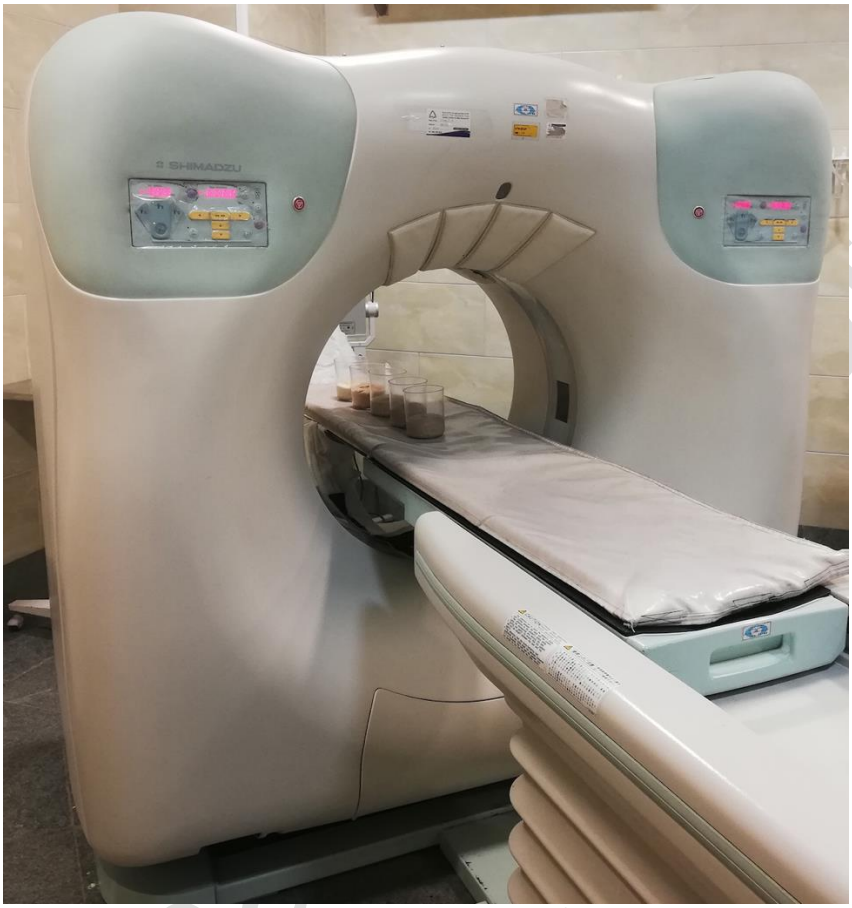
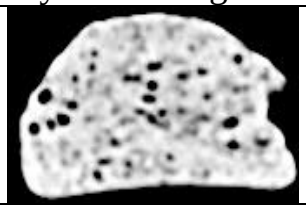


Fig 1. X-ray Computed Tomography Imaging of 5 dough samples

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Dough sample	Gray scale Image	Binary Image
1- No bran		

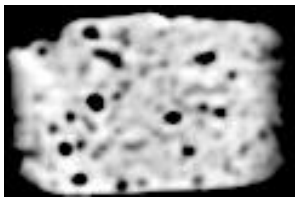
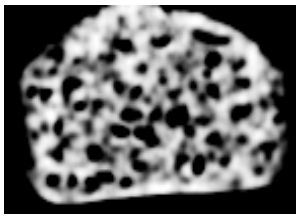
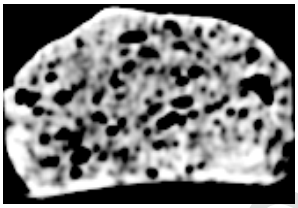
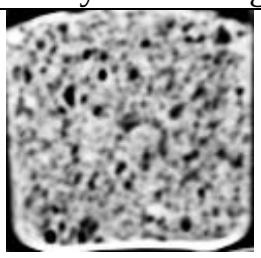
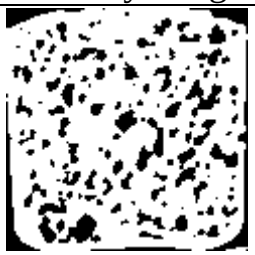
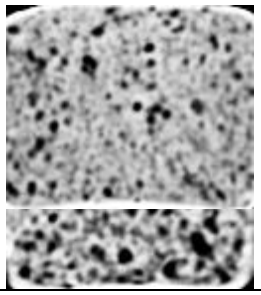
2- 15% raw bran		
3- 9% hydrothermal bran		
4- 15% hydrothermal bran		
5- 15% hydrothermal bran with an excess amount of sugar and improver		

Fig 2. X-ray Computed Tomography Images of five dough samples after 60 min of fermentation.

Dough sample	Gray scale Image	Binary Image
1- No bran		
2- 15% raw bran		
3- 9% hydrothermal bran		

4- 15% hydrothermal bran

5- 15% hydrothermal bran with an excess amount of sugar and improver

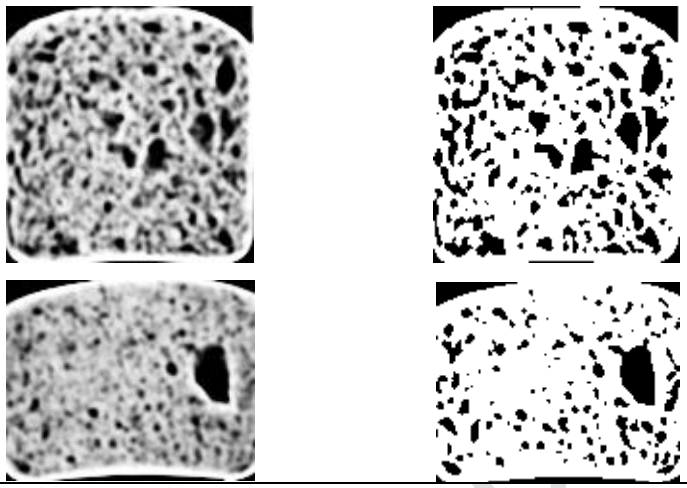


Fig 3. X-ray Computed Tomography Images of five dough samples after 120 min of fermentation.

Table1. Pore structure parameters of five dough samples measured at the first (H1) and second (H2) hour of CT imaging.

Dough sample	*Surface porosity (%)*	*Average pore area (Pixel)*	*Average pore diameter (Pixel)*
No bran	***H1:18.03***	***H1:33.13***	*H1:5.94*
	H2:27.50	***H2:40.43***	*H2:5.17*
15% raw bran	***H1:31.79***	***H1:60.60***	*H1:6.77*
	H2:32.77	***H2:40.88***	*H2:5.75*
9% hydrothermal bran	***H1:13.48***	***H1:19.74***	*H1:4.31*
	H2:21.70	***H2:25.71***	*H2:4.47*
15% hydrothermal bran	***H1:30.27***	***H1:52.27***	*H1:6.37*
	H2:33.95	***H2:45.45***	*H2:5.71*
15% hydrothermal bran with an excess amount of sugar and improver	***H1:18.22***	***H1:29.09***	*H1:5.17*
	H2:25.63	***H2:38.15***	*H2:5.01*

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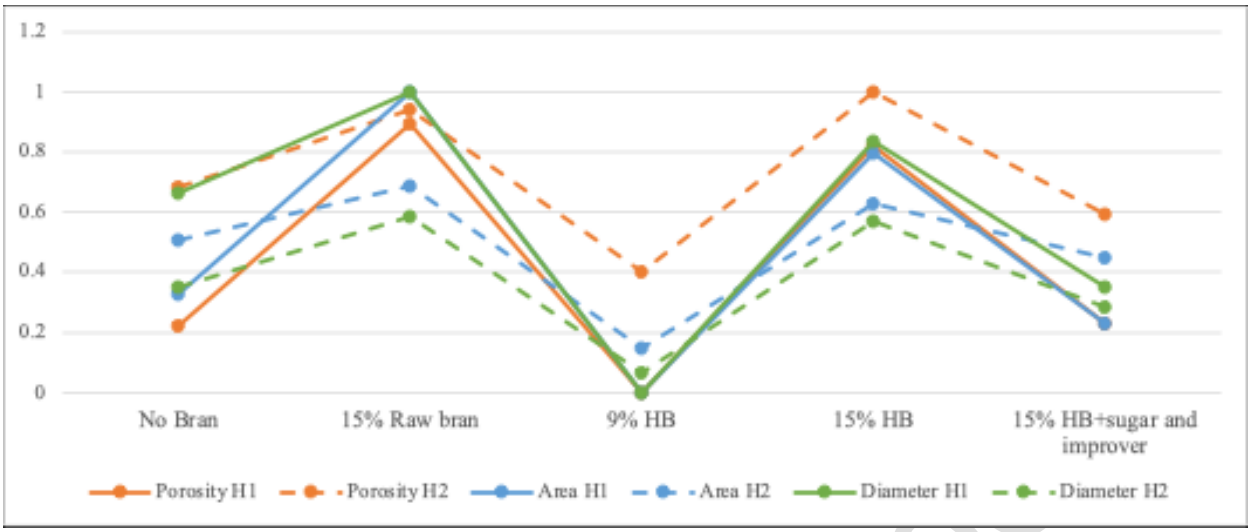


Fig. 4 Normalized evolution of surface porosity, mean pore area, and mean pore diameter of five dough samples at 60 min (H1) and 120 min (H2) hour of CT imaging. Values were normalized to the control sample. HB denotes hydrothermal bran

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