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# Characterization of Dough Rheological Properties and Bread Quality from Different Triticale Varieties and Fermented Dark Brewers' Spent Grain

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## Abstract

Triticale grains and brewers' spent grain (BSG) offer promising, sustainable ingredients for bread development, as triticale adapts well to climate change and BSG is a low-cost by-product supporting zero-waste goals. This study evaluated the rheological properties of dough and bread quality obtained from seven triticale cultivars (Ingen 35, Ingen 93, Ingen 40, Ingen 33, Ingen 54, Costel, and Fanica) grown in the Republic of Moldova, with the addition of 5% and 10% fermented dark BSG (BSGF). BSGF incorporation decreased dough stability and protein network strength, as indicated by Mixolab parameters, while the pasting properties varied according to the cultivar. Dynamic rheology showed reductions in storage (G′) and loss (G″) moduli, with tan δ < 1 for all samples. Increasing BSGF levels reduced falling number, Alveograph tenacity, extensibility, baking strength, and Rheofermentometer parameters. In bread, BSGF addition decreased loaf volume and porosity while significantly increasing acidity. Color analysis showed reduced lightness (L*) and increased redness (a*). Texture profile analysis indicated increased hardness and adhesiveness, with stable cohesiveness and reduced resilience. Sensory evaluation revealed improved color and a "hearty" texture at 5% inclusion, whereas 10% resulted in a denser structure and lower acceptability. BSGF significantly influenced the rheological, physicochemical, and sensory properties of triticale bread, highlighting the need for formulation optimization.

**Keywords:** triticale bread; rheological behavior; bread quality; brewer's spent grain



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## References


1. Andras, B.E.; Fițiu, A.; Acs, P.B.; Horga, V.A.; Racz, I.; Duda, M.M. The Influence of Sowing Rate and Foliar Fertilization on the Yield of Some Triticale Varieties in the Context of Climate Change in Northwest Romania. *Agriculture* **2024**, *14*, 2155. [CrossRef]
2. Food and Agriculture Organization of the United Nations (FAO). Crops and Livestock Products. Available online: https://www.fao.org/faostat/en/#data/QCL (accessed on 23 February 2026).
3. Usmanova, M.; Urokov, S.; Xadjayev, D.; Jurayeva, Z.; Keldiyarova, X.; Valiyev, S. The influence of conditions on water holding capacity characteristics of triticale varieties planted in the Samarkand region. *Plant Sci. Today* **2024**, *11*, 752–760. [CrossRef]
4. Cionca, I.; Luput, I.; Rusu, T. Triticale: Navigating Past Achievements, Current Realities and Future Horizons in Agricultural Innovation. *Agricultura* **2024**, *129*, 1–2.
5. Rodríguez-Pérez, G.; Cervantes-Ortiz, J.F.; Gámez-Vázquez, A.J.; Reynaga-Franco, F.J.; Torres-Velázquez, J.R.; Ávila-Perches, M.Á. Nutritional value in grains of triticale as an alternative in the food industry. *Rev. Mex. Cienc. Agric.* **2023**, *14*, 351. [CrossRef]
6. Andraș, B.-E.; Ács, B.; Racz, I.; Ursan, P.; Duda, M. Triticale, a Grain with Many Uses, Including Medicinal. *Hop Med. Plants* **2023**, *31*, 93–109. [CrossRef]
7. Kaszuba, J.; Jaworska, G.; Krochmal-Marczak, B.; Kogut, B.; Kuźniar, P. Effect of bran addition on rheological properties of dough and quality of triticale bread. *J. Food Process. Preserv.* **2021**, *45*, e15093. [CrossRef]
8. Pycia, K.; Kaszuba, J.; Posadzka, Z.; Juszczak, L. Influence of the Addition of Vital Wheat Gluten on Thermal and Rheological Properties of Triticale Flour. *Polymers* **2023**, *15*, 1870. [CrossRef]
9. Tamagno, S.; Pittelkow, C.M.; Fohner, G.; Nelsen, T.S.; Hegarty, J.M.; Carter, C.E.; Vang, T.; Lundy, M.E. Optimizing water and nitrogen productivity of wheat and triticale across diverse production environments to improve the sustainability of baked products. *Front. Plant Sci.* **2022**, *13*, 952303. [CrossRef]
10. González-Alonso, V.; Pradal, I.; Wardhana, Y.R.; Cnockaert, M.; Wieme, A.D.; Vandamme, P.; De Vuyst, L. Microbial ecology and metabolite dynamics of backslopped triticale sourdough productions and the impact of scale. *Int. J. Food Microbiol.* **2024**, *408*, 110445. [CrossRef]
11. Suhovici, D.; Paiu, S.; Rumeus, I.; Boeştean, O.; Codină, G.G.; Ghendov-Mosanu, A. Current and prospective directions in the use of the grain crops triticale. *J. Eng. Sci.* **2025**, *32*, 136–150. [CrossRef]
12. Statista Inc. Beer Production Worldwide from 1998 to 2024. *Statista* **2025**. Available online: https://www.statista.com/statistics/270275/worldwide-beer-production/ (accessed on 23 February 2026).
13. Dancker, P.; Glas, K.; Gastl, M. Potential utilisation methods for brewer's spent grain: A review. *Int. J. Food Sci. Technol.* **2025**, *60*, vvae022. [CrossRef]
14. Chetrariu, A.; Dabija, A. Spent Grain: A Functional Ingredient for Food Applications. *Foods* **2023**, *12*, 1533. [CrossRef]

15. Farcas, A.C.; Chis, M.S.; Socaci, S.A.; Dulf, F.; Podea, P.; Salanta, L.C.; Paucean, A.; Negrean, O. Craft Brewers' Spent Grains as a Secondary Resource: Chemical Profiling of Key Nutritional Components. *Agriculture* **2026**, *16*, 720. [CrossRef]
16. Ressa, A.; Nyhan, L.; Sanchez, R.; Lombardi, D.N.; O'Riordan, P.; Arendt, E.K. In vitro protein digestibility and protein quality assessment of novel brewers' spent grain protein isolates. *Innov. Food Sci. Emerg. Technol.* **2026**, *109*, 104482. [CrossRef]
17. Pérez-Alva, A.; Martín del Campo, S.T.; Baigts-Allende, D.K. Brewer's spent grain (BSG) as an ingredient for leavened bread making: Challenges and opportunities. *J. Cereal Sci.* **2025**, *124*, 104223. [CrossRef]
18. Cheung, J.; Hwang, E.S. Quality and Functional Characteristics of Morning Bread Supplemented with Brewer's Spent Grain Powder. *Prev. Nutr. Food Sci.* **2026**, *31*, pnf.2025.259. [CrossRef]
19. Aprodu, I.; Simion, A.B.; Banu, I. Valorisation of the brewers' spent grain through sourdough bread making. *Int. J. Food Eng.* **2017**, *13*, 201700195. [CrossRef]
20. Neylon, E.; Arendt, E.K.; Zannini, E.; Sahin, A.W. Fermentation as a tool to revitalise brewers' spent grain and elevate techno-functional properties and nutritional value in high fibre bread. *Foods* **2021**, *10*, 1639. [CrossRef] [PubMed]
21. Goh, L.L.; Chi Lik Lee, K. Biovalorisation of brewer's spent grain (BSG) and sensory evaluation of BSG bread. *ChemRxiv* **2021**.
22. Amoriello, T.; Mellara, F.; Galli, V.; Amoriello, M.; Ciccoritti, R. Technological properties and consumer acceptability of bakery products enriched with brewers' spent grains. *Foods* **2020**, *9*, 1492. [CrossRef] [PubMed]
23. Vriesekoop, F.; Haynes, A.; van der Heijden, N.; Liang, H.; Paximada, P.; Zuidberg, A. Incorporation of fermented brewers spent grain in the production of sourdough bread. *Fermentation* **2021**, *7*, 96. [CrossRef]
24. Waters, D.M.; Jacob, F.; Titze, J.; Arendt, E.K.; Zannini, E. Fibre, protein and mineral fortification of wheat bread through milled and fermented brewer's spent grain enrichment. *Eur. Food Res. Technol.* **2012**, *235*, 767–778. [CrossRef]
25. Ghendov-Mosanu, A.; Ropciuc, S.; Dabija, A.; Saitan, O.; Boestean, O.; Paiu, S.; Rumeus, I.; Leatamborg, S.; Lupascu, G.; Codină, G.G. Effect of Brewers' Spent Grain Addition to a Fermented Form on Dough Rheological Properties from Different Triticale Flour Cultivars. *Foods* **2025**, *14*, 41. [CrossRef] [PubMed]
26. International Association for Cereal Science and Technology (ICC). *ICC Standard Methods*; 104/1, 136, 105/2, 110/1, 173; ICC121; ICC: Vienna, Austria, 2005.
27. Codină, G.G.; Ursachi, F.; Dabija, A.; Paiu, S.; Rumeus, I.; Leatamborg, S.; Lupascu, G.; Stroe, S.-G.; Ghendov-Mosanu, A. Physicochemical Properties, Polyphenol and Mineral Composition of Different Triticale Varieties Cultivated in the Republic of Moldova. *Molecules* **2025**, *30*, 1233. [CrossRef] [PubMed]
28. *SR 90:2007*; Wheat Flour. Analysis Methods. ASRO Publisher House: Bucharest, Romania, 2007.
29. *SR 91:2007*; Bread and Fresh Pastries. Analyses Methods. ASRO Publisher House: Bucharest, Romania, 2007.
30. *ISO 6658:2017*; Sensory Analysis—Methodology—General Guidance 2017. International Organization for Standardization (ISO): Geneva, Switzerland, 2017.
31. *ISO 8589:2007*; Sensory Analysis. General Guidance for the Design of Test Rooms. International Organization for Standardization (ISO): Geneva, Switzerland, 2007.
32. Lovegrove, A.; Wood, A.J.; Hassall, K.L.; Howes, L.; Poole, M.; Tosi, P.; Shewry, P.R. The contribution of fiber components to water absorption of wheat grown in the UK. *Cereal Chem.* **2020**, *97*, 940–948. [CrossRef]
33. Lauková, M.; Kohajdová, Z.; Karovičová, J.; Kuchtová, V.; Minarovičová, L.; Tomášiková, L. Effects of cellulose fiber with different fiber length on rheological properties of wheat dough and quality of baked rolls. *Food Sci. Technol. Int.* **2017**, *23*, 490–499. [CrossRef]
34. Stojceska, V.; Ainsworth, P. The effect of different enzymes on the quality of high-fibre enriched brewer's spent grain breads. *Food Chem.* **2008**, *110*, 865–872. [CrossRef]
35. Rössel, B.; Salmenkallio-Marttila, M.; Suortti, T.; Holt, M. Wheat flour non-starch polysaccharides and their effect on dough rheological properties. *Ind. Crops Prod.* **2011**, *34*, 1327–1331. [CrossRef]
36. Rosell, C.M.; Rojas, J.A.; Benedito de Barber, C. Influence of cellulosic fibres on pasting properties of starch–fibre blends. *Int. J. Food Sci. Technol.* **2010**, *45*, 1641–1648.
37. Zou, X.; Wang, X.; Li, L.; Peng, P.; Ma, Q.; Hu, X.; Appels, R. Effects of composition and strength of wheat gluten on starch structure, digestion properties and the underlying mechanism. *Foods* **2022**, *11*, 3432. [CrossRef]
38. Ghendov-Mosanu, A.; Popa, N.; Paiu, S.; Boestean, O.; Bulgaru, V.; Leatamborg, S.; Lupascu, G.; Codină, G.G. Breadmaking Quality Parameters of Different Varieties of Triticale Cultivars. *Foods* **2024**, *13*, 1671. [CrossRef] [PubMed]
39. Axentii, M.; Stroe, S.-G.; Codină, G.G. Development and Quality Evaluation of Rigatoni Pasta Enriched with Hemp Seed Meal. *Foods* **2023**, *12*, 1774. [CrossRef] [PubMed]
40. Struck, S.; Straube, D.; Zahn, S.; Rohm, H. Interaction of wheat macromolecules and berry pomace in model dough: Rheology and microstructure. *J. Food Eng.* **2018**, *223*, 109–115. [CrossRef]
41. Abebe, W.; Ronda, F.; Villanueva, M.; Collar, C. Effect of tef [*Eragrostis tef* (Zucc.) Trotter] grain flour addition on viscoelastic properties and stickiness of wheat dough matrices and bread loaf volume. *Eur. Food Res. Technol.* **2015**, *241*, 469–478. [CrossRef]

42. Verbeke, C.; Debonne, E.; Versele, S.; Van Bockstaele, F.; Eeckhout, M. Technological evaluation of fiber effects in wheat-based dough and bread. *Foods* **2024**, *13*, 2582. [CrossRef]
43. Plessas, S.; Trantallidi, M.; Bekatorou, A.; Kanellaki, M.; Nigam, P.; Koutinas, A.A. Immobilization of kefir and Lactobacillus casei on brewery spent grains for use in sourdough wheat bread making. *Food Chem.* **2007**, *105*, 187–194. [CrossRef]
44. Pereira de Freitas, F.P.; da Silva Lannes, S.C. Composition and sensory properties of breads supplemented with brewers' spent grain from three different craft beer styles. *Cereal Chem.* **2024**, *101*, 1150–1159. [CrossRef]
45. Cheng, J.; Zheng, L.; Zhao, J.; Yu, M.; Cao, R.; Wang, D.; Li, J.; Zhou, L. Study on the effect of microwaved brewer's spent grains on the quality and flavor characteristics of bread. *Foods* **2024**, *13*, 461. [CrossRef]
46. Zhang, Y.; Wei, X.; Bao, J.; Xu, K.; Chen, X.; Guo, M. Applicability of wheat brewer's spent grain in steamed bread-making based on physicochemical and visual profiles assessment of doughs and breads. *Food Sci. Technol. Int.* **2024**, *32*, 10820132241260453. [CrossRef]
47. Sato, Y. Structural recoverability of white breads based on the "cohesiveness" value from texture profile analysis and the "compression force value" from the American Association of Cereal Chemists (74–09). *J. Texture Stud.* **2025**, *56*, e70028. [CrossRef] [PubMed]
48. Codină, G.G.; Bordei, D.; Pâslaru, V. The effects of different doses of gluten on rheological behaviour of dough and bread quality. *Roum. Biotechnol. Lett.* **2008**, *13*, 37–42.
49. Heuven, L.A.J.; Dekker, M.; Renzetti, S.; Bolhuis, D.P. The eating rate of bread predicted from its sensory texture and physical properties. *Food Funct.* **2024**, *15*, 12244–12255. [CrossRef]
50. Baiano, A.; La Gatta, B.; Rutigliano, M.; Fiore, A. Functional bread produced in a circular economy perspective: The use of brewers' spent grain. *Foods* **2023**, *12*, 834. [CrossRef]