Light brewer's spent grain as a functional ingredient in sourdough triticale bread production

Iurie Rumeus[1,2], Sorina Ropciuc[3], Olesea Saitan[1], Aliona Ghendov-Mosanu[1], Viorica Bulgaru[1], Svetlana Leatamborg[4], Galina Lupascu[4], Georgiana Gabriela Codină[3]

1 – Technical University of Moldova, Chisinau, Moldova
2 – Cahul University Center "Bogdan Petriceicu Hasdeu" of Technical University of Moldova
3 – Ştefan cel Mare University, Suceava, Romania
4 – Institute of Genetics, Physiology and Plant Protection, Moldova State University, Chisinau, Moldova

Keywords:

Triticale
Brewer's spent grains
Fermentation
Dough
Rheological properties
Bread
Quality

Article history:

Received 27.09.2025
Received in revised form 14.02.2026
Accepted 31.03.2026

Corresponding author:

Georgiana Gabriela Codină
E-mail: codina@fia.usv.ro

DOI: 10.24263/2304-974X-2026-15-1-8

Abstract

Introduction. The aim of the research is to determine the effect of light brewer's spent grain in a sourdough form (BSF) on dough rheological properties and bread quality obtained from three different triticale varieties Ingen 40, Costel and Fanica.

Materials and methods. The rheological properties of triticale dough were evaluated using Mixolab, Alveograph, Falling Number, Rheofermentometer, and a HAAKE MARS 40 rheometer, while bread quality was assessed in terms of acidity, loaf volume, porosity, elasticity, texture, color parameters, and sensory attributes based on a 9-point hedonic scale.

Results and discussion. The incorporation of light brewer's spent grain in sourdough form into the dough recipe led to a significant decrease in water absorption, dough stability, dough development time, protein weakening (C2), dough storage and loss moduli (G′, G″), dough tenacity, baking strength, and P/L ratio, indicating a weakening of the dough rheological properties. BSF addition significantly increased α-amylase activity, as evidenced by the decrease in falling number values. Mixolab analysis showed that the difference between C3 (starch gelatinization) and C4 (hot gel stability) reflected amylolytic activity and exhibited some fluctuations, likely due to incomplete starch gel formation. BSF also reduced starch gelatinization, as indicated by the decrease in C3 torque. Rheological properties during fermentation improved, with retention coefficients above 90%, indicating the potential to obtain good-quality bread. BSF incorporation resulted in triticale bread of good quality, contributing nutty, earthy, and malty notes that enhanced acceptability. However, it increased acidity and decreased loaf volume, porosity, and elasticity, while modifying textural characteristics.

Conclusion. Bread enriched with light brewer's spent grains in a sourdough form presents a promising avenue for creating value-added, sustainable, and nutritious triticale-based products that appeal to modern consumers seeking healthier and environmentally conscious food choices.

Introduction

Current global challenges due to climate change, rapid population growth, and current consumer preference for healthier foods have led to the search for alternative solutions to traditional cereals used in human nutrition. One such solution is triticale, which is the first cereal obtained from artificial hybridization between tetraploid wheat (*Triticum aestivum*) and rye (*Secale cereale*). In 2022, the top ten triticale producers in the world, by area cultivated and share, were: Poland (34.1%), Belarus (11.2%), France (9.4%), Germany (9%), Spain (7.8%), China (5.5%), Turkey (2.8%), Lithuania (1.7%), Australia (1.7%), and Romania (1.6%) (a5), with more than 90.0% of triticale production being concentrated in Europe (González-Alonso et al., 2024).

By creating this species, the most valuable traits of wheat (functional qualities for food production, early maturity, high grain number per ear, and high grain weight) were combined with the valuable traits of rye (resistance to drought, heat, diseases, pests, and high adaptability to damaged soils and unfriendly areas) (Andraș et al., 2023; Bonea, 2024; Cionca et al., 2024; Vaca-García et al., 2011). Triticale is a highly productive crop even in environments inaccessible to other food crops, with low production costs compared to other crops, and with low sensitivity to biotic and abiotic stress factors (Leonova et al., 2022; Usmanova et al., 2024).

New technologies used in baking or by adding ingredients can produce quality products that are accepted by consumers (Shevchenko, 2022; Shevchenko et al., 2024; Tsykhanovska et al., 2024). Adding potato maltodextrins to triticale flour, mixing triticale flour with 5% and 10% bran or combining several cereals (e.g. wheat, rye and triticale in a ratio of 40:50:10 or 90:10) have shown great promise in producing quality bakery products (Bonea, 2024). Triticale noodles have higher nutritional value and bioactivity compared to conventional wheat noodles, due to the higher content of proteins, minerals, vitamins and phenolic compounds (Liu et al., 2023).

In addition to its high nutritional value, the development of whole grain triticale flour bakery products is also due to the health benefits of these functional products recommended for their antioxidant, anticancer and cardiovascular disease prevention properties (Banu et al., 2020; Li et al., 2024). In general, triticale grains help control diabetes, improve gastrointestinal health, stimulate circulation, increase cell production and stimulate bone growth (Arizmendi-Cotero et al., 2020; Piazza et al., 2023).

Barley spent grain (BSG) is the main by-product of the brewing industry, accounting over 85% of beer manufacturing by-products (Hejna, 2021). Its bioconversion from waste into a useful ingredient aligns with the increasing interest in sustainable and resource-efficient food production (Stabnikova et al., 2023a, b). Barley spent grain is in specially composed from the husk and outer layers of the barley kernel and is rich in dietary fiber, protein, essential amino acids, minerals, and bioactive compounds (Chetrariu and Dabija, 2023; Ivanov et al., 2021). Despite its high nutritional value, approximately 70% of barley spent grain is utilized as animal feed, 10% is converted into biogas and 20% are disposed in landfills (Mitri et al., 2022). The increasing interest in sustainable food systems and circular economy practices had encouraged the incorporation of barley spent grain into food products, such as bakery ones. However, the use of BSG in its current form does not lead to a full valorisation of its nutritional characteristics. It has been reported that BSG presents some antinutritional factors, a low mineral bioavailability and protein digestibility which may be improved by different preliminary treatments such as fermentation ones (Chetrariu and Dabija, 2023; Henkin et al., 2025). Through fermentation complex fibers are partially broken down, bioavailability of nutrients is enhanced, and antinutritional factors are reduced. More, the fermentation process may contribute to the improvement of BSG aromas and dough rheology and bread quality (Ghendov-Mosanu, 2024).

The aim of this work was to establish the possibility of using wholemeal flours from three different varieties of triticale (Ingen 40, Costel, Fanica) cultivated in the Republic of Moldova in breadmaking, and to evaluate the influence of the addition of sourdough from light brewers' spent grain flour on dough rheology and bread quality.

Materials and methods

Materials

Three triticale varieties (Ingen 40, Costel, Fanica) cultivated in the Republic of Moldova (harvest 2023) were used in this study. To obtain integral triticale flour, the grains were milled in a laboratory mill 3100 (Perten Instruments, Hägersten, Sweden) and presented the fallowing data according to the ICC (International Association for Cereal Science and Technology) standard methods: 13.1–14.2% for protein content (ICC 105/2), 1.50–1.70% for ash content (ICC 104/1), and 18.49–25.61% for wet gluten content (ICC 106/2). The brewers' spent grain (BSG) was obtained from the blonde beer process. (Î.M. "Efes Vitanta Moldova Brewery" S.A., Chisinau, the Republic of Moldova). Sourdough from brewers' spent grain flour had been obtained according to the method previously described (Ghendov-Mosanu et al., 2025). The BSG in a fermented form (BSF) were incorporated in 10 and 17.5% levels in triticale flour.

Evaluation of dough rheological properties

Dough mixing and pasting rheological properties were determined using the Mixolab device (KPM, Tripette et Renaud, Paris, France) according to the ICC No. 173 standard method. The Mixolab parameters analysed were water absorption (WA), dough development time (DDT), dough stability (ST) and torques during mixing and heating C1-C5.

Dynamic dough rheological properties have been determined using HAAKE MARS 40 rheometer (Thermo-HAAKE, Karlsruhe, Germany). Frequency sweep tests from 1 to 20 Hz were carried out in which the storage modulus (G') and the loss modulus (G"), were obtained together with the phase change according to the method previously described by Ghendov-Mosanu et al. (2025).

Evaluation of dough rheological properties during extension have been determined using an Alveograph (KPM, Tripette et Renaud, Paris, France) according to ICC 121 standard method on which dough extensibility (L), index of swelling (G), maximum pressure (P), baking strength (W) and configuration ratio (P/L) have been determined.

Rheological properties during fermentation have been determined using a rheofermentometer device (Chopin Rheo, type F4, KPM, Tripette et Renaud, Paris, France) in which the fallowing parameters have been determined: volume of the gas retained in the dough at the end of the test (VR, mL), total CO_2 volume production (VT, mL), retention coefficient (CR, %) and maximum height of gaseous production (H'm, mm) according to the method described by us in our previously study (Ghendov-Mosanu et al., 2025). Also, by using a Falling Number device (FN 1305, Perten Instruments AB, Stockholm, Sweden) the falling number (FN, s) value has been determined according to ICC 107/1 standard method.

Bread-making

For bread-making the dough has been prepared through the direct method. Salt, compressed yeast (*Saccharomyces cerevisiae*), triticale flour, water and sourdough from brewers' spent grain were mixed for 10 – 15 min in a laboratory mixer (Kitchen Aid, Whirlpool Corporation, Benton Harbor, MI, USA). Dough was fermented in a Cooper 72B device (Europe SRL, Malo (VI), Italy) at a temperature of 30±1°C for 120 – 150 min. The dough was divided into 400 g pieces, modelled and finally proofed at a temperature of 38±1°C and a relative humidity of 80 – 85% for 50 min. The dough was steamed and baked in a Cooper 72B oven (Europe SRL, Malo (VI), Italy) at a temperature of 190±10 °C for 50 – 60 min. After baking, the bread samples were cooled to a temperature of 20±1 °C, after which the quality characteristics were analysed.

Bread quality characteristics

The bread was evaluated for its physical, textural, color and sensory characteristics. Loaf volume, porosity, elasticity was determined according to the AACC (2010). The bread acidity was determined according to the method described by Ghendov-Mosanu et al. (2024). The textural characteristics of the bread samples were determined using a Stable Micro Systems TA.HD plus C texture analyzer (United Kingdom) on which the following parameters were determined: firmness, gumminess, cohesiveness, chewiness and resilience. For this purpose, bread slices of 20×20 mm was subjected to a two-compression cycle with a P/75 stainless steel plate, by the following protocol: pre-test speed - 100 m/s; test speed - 5 m/s; post-test speed - 5 m/s and cell load - 5 kg. The color parameters were determined using a Konica Minolta CR-400 colorimeter (Tokyo, Japan). The following parameters were determined: L* (darkness/lightness), a* (red/green tone) and b* (blue/yellow tone). The determinations were based on the CIELab* system. The range in which the absorption of electromagnetic radiation was performed was the UV-vis. Bread sensory characteristics were analyzed using the 9-point hedonic scale with semi-trained panelists. The fallowing sensory characteristics were analyzed: appearance, color, taste, odor, texture, aroma and global acceptability.

Statistical analysis

The data obtained were analysed by using the analysis of variance (ANOVA) and Tukey's test ($p < 0.05$). All calculations were determined using Statgraphics software Centurion XVI 16.1.17 (Statgraphics Technologies, Inc., The Plains, VA, USA).

Results and discussion

Light brewers' spent grain sourdough effect on dough rheological properties

The rheological behavior of the dough during mixing and heating was evaluated using the Mixolab device, which provides key parameters reflecting protein and starch transformations: the C1 value represents the initial dough consistency and water absorption capacity; C2 indicates protein weakening and thus reflects the stability of the gluten network under mechanical and thermal stress; C3 corresponds to starch gelatinization, describing the swelling of starch granules during heating; C4 reflects the stability of the hot starch gel and is associated with enzymatic activity, particularly that of α-amylase; finally, C5 represents starch retrogradation during cooling and is related to bread staling.

The dough mixing and pasting properties of triticale dough with different amounts of sourdough addition are shown in Table 1. As may be seen, water absorption value significantly ($p < 0.05$) decreased by brewers' spent grain addition in a fermented form in dough recipe (BSF), these data being in disagreement with those reported by Aprodu et al. (2017) when BSG was added into wheat flour. Generally, dough stability and dough development time decreased or did not present high variations compared to the control sample. This decrease indicates a weakening of the dough probably due to the gluten dilution since BSF does not contain gluten. The C1 torque is around 1.1 N·m which is the typically adjusted value to Mixolab protocol to determine the proper water absorption value (Golea et al., 2023). The C2 Mixolab torque value indicates the protein weakening which decreased with the increases amount of BSF addition in dough recipe. Because gluten is in a lower amount and also due to the fact that light brewers' spent grain is incorporated in the dough recipe in a sourdough form dough viscosity decreased during heating favouring protein denaturation and an increase of proteolytic enzymes activity fact reflected by a decrease of C2 and an increase of C12 values from the Mixolab curve (Dabija et al., 2017). The C3 values which represent starch gelatinization behaviour decreased with the increase amount of BSF addition in wheat flour. By BSF addition, which is in a high level, the starch amount from the dough system decreased. More, the amount of water is less, which indicates than the starch gelatinisation may not be complete. However, the difference between C3 and C2 torques presented fluctuations probably due to the water availability in the dough system and the ability of starch to gelatinize in a more or less completely form (Codină et al., 2019). The same behaviour may be related to C4 and the difference between C4 and C3 torques (C34). C34 values are related to the amylolytic enzyme activity and therefore the higher the value of this parameter is, the higher the enzymatic activity of amylases are. However, the amylase activity is related to the starch gelling. If the starch gelatinisation is not complete, then the amylolytic activity may be lower. C5 value which is related to the final starch paste viscosity and the difference between C5 and C4 torques (C54) presented some fluctuations probably due to the BSF chemical composition such as non-gluten proteins, nonstarch polysaccharides which modifies three-dimensional network of the dough system (Ghendov-Mosanu et al., 2025).

Frequency sweep behaviour of the dough samples with and without BSF addition are shown in Figure 1. As may be seen, loss (G″) and storage (G′) module increased with frequency. For all samples, the *G″* was lower than *G′* indicating a solid-like behaviour (Tan et al., 2023). Higher amounts of BSF led to a decrease of G′ and G″ values which indicates a decrease of dough viscoelasticity. This may be due to the decrease of gluten content from the dough system which is the mainly responsible for dough viscoelasticity properties. Loss tangent (tan δ) is less than 1 for all dough samples indicating that dough has dominant elastic properties (Li et al., 2023). The BSF addition in dough recipe increases tan δ values which indicates the fact that these samples have a more pronounced viscous component, which can negatively influence bread shape stability and textural properties.

Dough rheological properties during extension are shown in Table 2. As may be seen the alveograph values P, W and the ratio P/L decreased by BSF addition in triticale flour. This indicates a dough weakness probably due to the gluten dilution but also due to the enzymatic activity from light brewers' spent grain sourdough addition which act on gluten and starch. The dough extensibility (L) and index of swelling (G) present some fluctuations for the samples with BSF addition in triticale flour. Generally, at low amounts of BSF addition in dough recipe, these values tend to increase, whereas at high addition levels these values significantly ($p < 0.05$) decreased. This behaviour is due to the enzymatic activity increase in dough system with BSF addition which hydrolyse and increase it extensibility. However, at high amount of BSF addition in triticale flour, it is possible that the dough pH values to reach the isoelectric ones and to modify gluten structure and therefore its extensibility. These data are in agreement with those reported by Codină et al. (2021) when sourdough were added in wheat flour.

Table 1

Mixolab values for triticale dough with light brewers' spent sourdough

Samples	WA (%)	ST (min)	DDT (min)	C1 (N·m)	C2 (N·m)	C3 (N·m)	C4 (N·m)	C5 (N·m)	C12 (N·m)	C32 (N·m)	C34 (N·m)	C54 (N·m)
Ingen 40	57.5±0.3 ^{e}	6.3±0.2 ^{d}	4.78±0.03 ^{f}	1.130±0.0 ^{e}	0.462±0.001 ^{f}	2.027±0.006 ^{d}	0.675±0.003 ^{f}	1.245±0.013 ^{e}	0.668±0.006 ^{a}	1.565±0.021 ^{e}	1.352±0.006 ^{f}	0.570±0.0 ^{f}
Ingen 40_10BSF	47.7±0.01 ^{c}	3.6±0.1 ^{c}	4.08±0.04 ^{e}	1.129±0.001 ^{e}	0.353±0.005 ^{c}	1.855±0.004 ^{c}	0.590±0.006 ^{d}	1.092±0.002 ^{d}	0.776±0.003 ^{f}	1.502±0.013 ^{d}	1.265±0.007 ^{e}	0.502±0.005 ^{e}
Ingen 40_17.5BSF	40.2±0.2 ^{b}	3.6±0.1 ^{c}	3.98±0.01 ^{d}	1.154±0.002 ^{f}	0.353±0.003 ^{c}	1.824±0.008 ^{c}	0.664±0.007 ^{e}	1.096±0.005 ^{d}	0.801±0.002 ^{g}	1.471±0.016 ^{d}	1.160±0.0 ^{d}	0.432±0.005 ^{d}
Costel	60.0±0.3 ^{e,f}	2.8±0.2 ^{b}	2.97±0.03 ^{a}	1.095±0.003 ^{c}	0.379±0.005 ^{d}	1.449±0.010 ^{b}	0.326±0.002 ^{c}	0.599±0.008 ^{c}	0.716±0.005 ^{c}	1.070±0.006 ^{b}	1.123±0.002 ^{d}	0.273±0.002 ^{c}
Costel_10BSF	48.2±0.1 ^{d}	2.3±0.1 ^{a}	3.00±0.02 ^{a}	1.070±0.002 ^{a,b}	0.303±0.004 ^{b}	1.392±0.008 ^{b}	0.245±0.001 ^{a}	0.439±0.013 ^{a}	0.767±0.004 ^{e}	1.089±0.015 ^{b}	1.147±0.007 ^{d}	0.194±0.006 ^{a}
Costel_17.5BSF	37.9±0.1 ^{a}	2.4±0.2 ^{a,b}	2.92±0.01 ^{a}	1.072±0.001 ^{b}	0.266±0.005 ^{a}	1.422±0.006 ^{b}	0.314±0.004 ^{b}	0.588±0.001 ^{b}	0.806±0.001 ^{h}	1.156±0.012 ^{c}	1.108±0.006 ^{b,c}	0.274±0.003 ^{c}
Fanica	60.2±0.1 ^{f}	2.5±0.2 ^{a,b}	3.45±0.04 ^{c}	1.112±0.004 ^{d}	0.421±0.002 ^{e}	1.416±0.011 ^{b}	0.302±0.005 ^{b}	0.552±0.015 ^{b}	0.691±0.001 ^{b}	0.995±0.009 ^{a}	1.114±0.004 ^{d}	0.250±0.007 ^{b}
Fanica_10BSF	48.0±0.2 ^{c,d}	2.6±0.2 ^{a,b}	3.07±0.02 ^{b}	1.120±0.002 ^{d,e}	0.358±0.003 ^{c}	1.375±0.004 ^{a}	0.339±0.012 ^{c}	0.578±0.011 ^{b}	0.762±0.003 ^{e}	1.017±0.012 ^{a}	1.036±0.003 ^{a}	0.239±0.009 ^{b}
Fanica_17.5BSF	39.6±0.2 ^{b}	2.7±0.1 ^{b}	3.07±0.01 ^{b}	1.069±0.001 ^{a}	0.314±0.003 ^{b}	1.386±0.005 ^{b}	0.319±0.001 ^{b}	0.534±0.009 ^{b}	0.755±0.006 ^{d,e}	1.072±0.015 ^{b}	1.067±0.006 ^{b}	0.215±0.004 ^{a}

Mixolab values: WA, water absorption; ST, stability, DDT, dough development time; C1-C5, torques corresponding stages 1-5 of the Mixolab curve; C12, difference of the torques C1 and C2; C32, difference of the torques C3 and C2; C34, difference of the torques C3 and C4; C54, difference of the torques C5 and C4. $^{a–h}$, mean values (n = 3) in the same column followed by different letters are significantly different (p < 0.05).

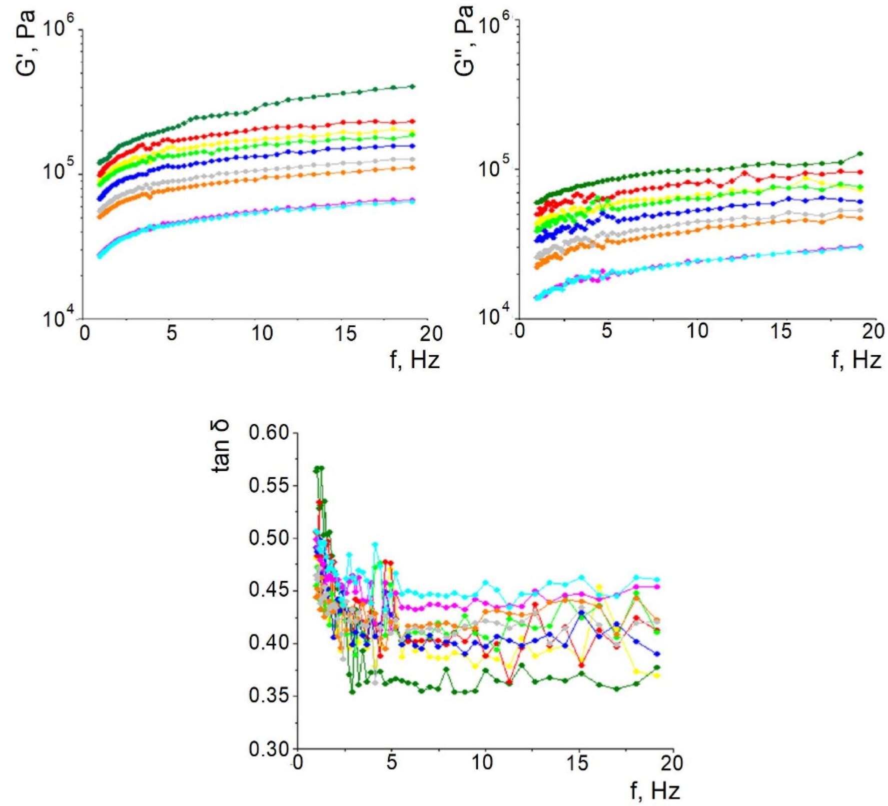


Figure 1. Evaluation with frequency of *G′*, *G″* and tan δ for dough samples (-●-Ingen 40; -●- Ingen40_10BSF; -●- Ingen40_17.5BSF; -●- Costel; -●- Costel 10BSF; -●- Costel 17.5BSF; -●- Fanica; -●- Fanica 10BSF; -●- Fanica 17.5BSF)

Table 2

Alveograph values for triticale dough with light brewers' spent sourdough

Samples	P (mm)	L (mm)	G (mm)	W (10^{-4} J)	P/L
Ingen 40	110±4 [f]	41±0 [c]	14.2±0.2 [e]	150±7 [e]	2.68±0.07 [e]
Ingen 40_10 BSF	52±6 [c]	52±1 [d]	16.0±0.3 [f]	64±0 [c]	1.00±0.09 [a]
Ingen 40_17.5 BSF	26±3 [a]	32±1 [b]	12.6±0.1 [d]	26±5 [a]	0.81±0.01 [a]
Fanica	125±4 [g]	33±0 [b]	12.8±0.2 [d]	147±3 [e]	3.79±0.08 [g]
Fanica_10BSF	67±6 d	31±1 [b]	12.4±0.1 [c,d]	61±2 [c]	2.16±0.11 [d]
Fanica_17.5BSF	43±1 [b]	23±1 [a]	10.6±0.1 [a]	22±2 [a]	1.87±0.09 [c]
Costel	99±7 [e]	32±1 [b]	12.6±0.1 [d]	104±5 [d]	3.09±0.06 [f]
Costel_10BSF	41±3 [b]	30±2 [b]	12.2± 0.1 [c]	44±3 [b]	1.37±0.13 [b]
Costel_17.5BSF	23±4 [a]	24±1 [a]	10.9±0.1 [b]	20±2 [a]	0.96±0.07 [a]

P, maximum pressure; L, dough extensibility; G, index of swelling; W, baking strength; P/L, configuration ratio of the Alveograph curve. [a–g], mean values (n = 3) in the same column followed by different letters are significantly different ($p < 0.05$).

Dough rheological properties during fermentation and the falling number values which expressed the α amylase activity are shown in Table 3. The BSF addition in triticale flour led to a significant ($p < 0.05$) decrease of the falling number values. This indicates an increase of the α amylase activity from the dough system probably due to the increase of amylolytic activity from the sourdough obtained from light brewers' spent grains. This increase will favour starch hydrolysis into maltose which will be consumed by yeast to produce carbon dioxide that increases Rheofermentometer parameters H'm and VT (Codină et al., 2013). As may be seen the VR values has also a similar trend as H'm and VT values even if triticale dough with BSF addition has a low gluten content. The CR coefficient, which is the ratio between VR and VT presents very good values higher than 90% which indicates a high ability of the dough samples to retain the gases formed during the fermentation process. This behaviour can positively influence bread loaf volume, porosity and textural properties according to Ktenioudaki et al. (2011). However, for Ingen 40 and Fanica samples with the highest amount of BSF incorporated in dough recipe the CR values begin to decrease probably due to the gluten dilution effect.

Light brewers' spent grain sourdough effect on bread quality characteristics

The bread samples obtained with different amount of BSF addition in triticale flour are shown in Figure 2.

Table 3

Rheofermentometer and falling number values for triticale dough with light brewers' spent sourdough

Samples	H'm (mm)	VT (mL)	VR (mL)	CR (%)	FN
Ingen 40	85.4±0.5 [b]	1607±26 [b]	1590±12 [b]	98.9±0.2 [d]	111±2 [e]
Ingen 40_10BSF	97.9±0.1 [e]	1645±31 [b]	1620±18 [b]	98.5±0.3 [c,d]	90±0 [d]
Ingen 40_17.5BSF	91.4±0.3 [d]	1865±19 [d]	1679±9 [b,c]	90.1±0.1 [a]	70±1 [b]
Costel	68.4±0.8 [a]	1328±7 [a]	1311±7 [a]	98.7±0.02 [c,d]	71±1 [b]
Costel 10BSF	90.2±0.1 [d]	1898±12 [d]	1872±11 [d]	98.6±0.02 [c,d]	67±1 [b]
Costel 17.5BSF	101.3±0.1 [f]	2229± 8 [f]	2212±14 [f]	99.2±0.03 [d]	64±1 [a]
Fanica	88.4±0.3 [c]	1648±11 [b]	1602±13 [b]	97.2±0.1 [b]	73±1 [c]
Fanica 10BSF	90.2±0.1 [d]	1752±14 [c]	1746±8 [c]	99.7±0.1 [d]	67±1 [b]
Fanica 17.5BSF	90.3±0.1 [d]	1988±9 [e]	1963±14 [e]	98.7±0.2 [c,d]	63±2 [a]

H'm, maximum height of gaseous production; VT, total CO_2 volume production; VR, volume of the gas retained in the dough at the end of the test; CR, retention coefficient. [a–f], mean values (n = 3) in the same column followed by different letters are significantly different ($p < 0.05$).

The bread physico-chemical characteristics are shown in Table 4. As may be seen, the acidity of the bread samples from triticale flours without the addition of sourdough from light brewers' spent grain flour varies between 4.60–6.46 degrees. At the same time, it can be noticed that the use of sourdough in the preparation of the dough influenced the increase of acidity of the bread samples by an average of 3 and 4.5 degrees when adding sourdough in an amount of 10% and 17.5% of the total flour mass. This increase of the acidity values can be explained by the intake of acids accumulated in the sourdough during the fermentation process (Ghendov-Mosanu et al., 2025).

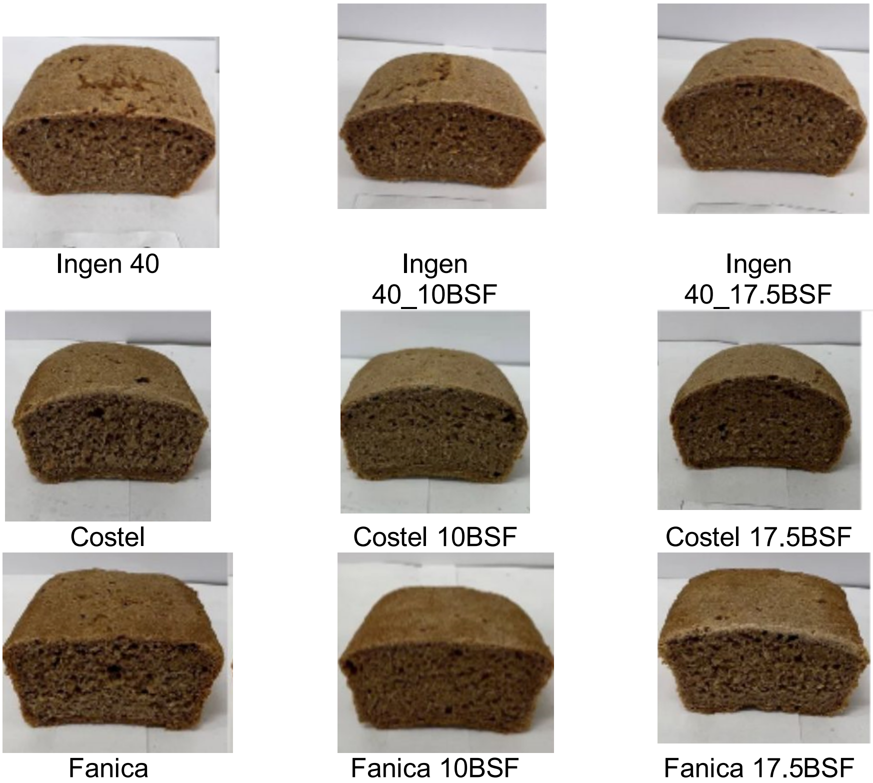


Figure 2. The triticale bread samples with different amount of BSF addition

Table 4

Physico-chemical characteristics values and global acceptability for triticale bread with light brewers' spent sourdough

Samples	Acidity (degrees)	Porosity (%)	Elasticity (%)	Loaf volume (cm^3/100g)	Global acceptability (dimensionless)
Ingen 40	4.60±0.02 ^{a}	58.3±0.6 ^{e}	67.3±0.6 ^{g}	239±4 ^{d,e}	8.62±0.05 ^{e}
Ingen 40_10BSF	8.08±0.01 ^{d}	53.0±0.3 ^{d}	62.1±0.1 ^{d}	217±3 ^{a,b}	8.55±0.03 ^{d,e}
Ingen 40_17.5BSF	9.84±0.02 ^{f}	52.9±0.1 ^{d}	58.7±0.2 ^{c}	216±5 ^{a,b}	8.00±0.0 ^{c}
Costel	5.70±0.03 ^{b}	51.3±0.2 ^{c}	64.8±0.1 ^{e}	260±4 ^{f}	8.43±0.03 ^{d}
Costel 10BSF	8.68±0.02 ^{e}	45.6±0.4 ^{b}	55.9±0.1 ^{b}	236±6 ^{c,d}	8.37±0.01 ^{d}
Costel 17.5BSF	10.70±0.04 ^{g}	44.3±0.2 ^{a}	53.7±0.2 ^{a}	216±3 ^{a,b}	7.18±0.04 ^{a}
Fanica	6.46±0.01 ^{c}	52.4±0.1 ^{c}	65.9±0.2 ^{f}	242±4 ^{d,e}	8.76±0.06 ^{e,f}
Fanica 10BSF	8.20±0.0 ^{d}	51.7±0.3 ^{c}	58.2±0.3 ^{c}	235±2 ^{c,d}	7.98±0.02 ^{c}
Fanica 17.5BSF	10.80±0.03 ^{g}	45.0±0.2 ^{b}	54.6±0.1 ^{b}	232±5 ^{c,d}	7.31±0.02 ^{b}

a–g, mean values (n = 3) in the same column followed by different letters are significantly different ($p < 0.05$).

The porosity and elasticity of the bread samples without the addition of sourdough from the brewers' spent grain flour varies between 51.3–58.3%, and 64.8–67.3% respectively, the highest value being obtained for the bread sample obtained from the Ingen 40 triticale flour variety. The variation in the porosity and elasticity of the bread samples can be explained by the variation in the chemical composition of triticale varieties (Codina et al., 2025), in particular by the variation in gluten proteins content, which plays the main role in the gluten formation process and influences the dough's ability to retain the gases formed during fermentation process. At the same time, the addition of sourdough from light brewers' spent grain flour in the bread recipe, significantly ($p < 0.05$) decreased the porosity and elasticity values. The loaf volume of bread samples without sourdough from light brewers' spent grain flour addition varied between 239–242 cm^3/100g. As may be seen the light brewers' spent sourdough addition decreased the values of bread samples. The explanation is similar to those for the porosity and elasticity decrease and namely doughs lose it ability to retain the gases formed during fermentation, as Rheofermentometer data has previously indicated.

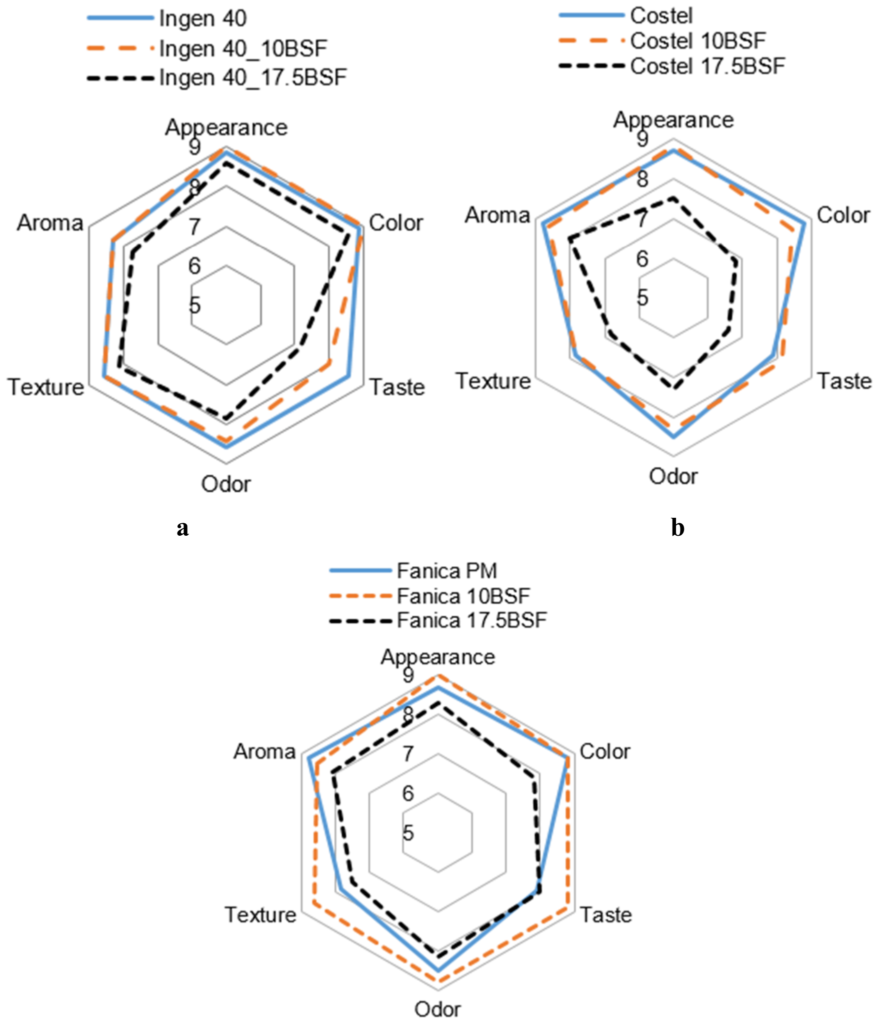
In the examined samples, the highest global acceptability values were recorded for the triticale bread samples without BSF addition (Table 4). The global acceptability scores ranged from 8.43 (Costel) to 8.76 (Fanica), while Ingen 40 showed an intermediate value of 8.62. Bread samples containing the lowest level of BSF addition (10%) exhibited global acceptability scores that did not differ significantly ($p > 0.05$) from those of the control samples (without BSF) in the case of Ingen 40 and Costel. For Fanica, however, BSF addition significantly affected global acceptability, resulting in a score of 7.98 ($p < 0.05$). Increasing the BSF concentration to 17.5% led to a decrease in global acceptability across all analysed samples, as illustrated by the sensory profile presented in Figure 3.

Sensory evaluation of the triticale bread samples indicated that the appearance of breads without BSF and with 10% BSF addition did not differ significantly (Figure 3).

In contrast, samples containing 17.5% BSF received lower appearance scores, falling below 8.0 in the case of the Costel and Fanica varieties. The addition of 17.5% BSF significantly affected crust color in the Costel and Fanica samples, with recorded values of 6.83 and 7.30, respectively. This effect can be attributed to crust browning caused by non-enzymatic reactions, including caramelization and the Maillard reaction (Pulis, 2010). Regarding crumb texture, the highest scores were obtained for all Ingen 40 bread samples. In contrast, Costel and Fanica samples containing 17.5% BSF received scores below 7.0, which may be explained by the high dietary fiber content of BSF and its impact on crumb structure.

Taste, odor, and aroma were influenced by both the dough preparation process and the ingredients used. Triticale bread enriched with BSF exhibited higher acidity, likely due to lactic acid formation during fermentation. The use of *Saccharomyces cerevisiae* contributed to a pleasant sensory profile, characterized by a mildly sweet taste and malt-like aroma, accompanied by typical cereal notes. Overall, sensory analysis demonstrated that triticale bread supplemented with 10% BSF was of very good quality.

The bread colour values are shown in Table 5. The colour of the bread samples was dark brown, characteristic to bakery products that are obtained from wholemeal flours. Positive values of parameters a* and b* indicate a shade of colour towards red and yellow. Also, a decrease in the lightness of the bread was found in the samples with the addition of sourdough from the light brewers' spent grain flour. The dark colour of the bread samples, can be explained, by the presence of flavone pigments from the alleuronic layer and grain shell particles, and also, due to the increasing intensity of the enzymatic hydrolysis of the starch and protein with the formation of simple carbohydrates and amino acids during bread-making for the samples with sourdough addition in bread recipe (Ghendov-Mosanu et al., 2024). This favours the Maillard reaction in the bread baking process which will increase the darkness of the bread samples.



c

Figure 3. Sensory characteristics of bread samples with different varieties of triticale with light brewers' spent sourdough:
a – Ingen 40; b – Costel; c – Fanica.

The bread textural characteristics are shown in Table 6. As may be seen, the hardness values vary between 21.25–53.14 N. By light brewers' spent sourdough addition in bread recipe the hardness value increased. This may be due to the increase in the content of bran particles into the bread due to the sourdough addition from the light brewers' spent grain flour.

Table 5

Colour values for triticale bread with light brewers' spent sourdough

Samples	CIELab color parameters		
	L*	a*	b*
Ingen 40	51.80±0.0 [e]	6.19±0.11 [c]	16.31±0.09 [a]
Ingen 40_10BSF	46.68±0.19 [d]	4.73±0.18 [a]	17.85±0.04 [b]
Ingen 40_17.5BSF	43.99±0.23 [c]	5.44±0.15 [b]	17.67±0.12 [b]
Costel	57.59±0.56 [f]	6.78±0.02 [c]	23.88±0.08 [c]
Costel 10BSF	46.22±0.31 [d]	5.15±0.04 [a]	33.21±0.11 [f]
Costel 17.5BSF	36.37±0.11 [a]	7.67±0.06 [d]	28.66±0.05 [d]
Fanica	50.44±0.22 [e]	10.72±0.08 [e]	35.00±0.10 [g]
Fanica 10BSF	41.83±0.17 [b]	5.72±0.11 [b]	33.15±0.13 [f]
Fanica 17.5BSF	37.19±0.11 [a]	5.77±0.04 [b]	30.16±0.09 [e]

L*, darkness/brightness; a*, shade of red/green; b*, shade of blue/yellow.
[a–g], mean values (n = 3) in the same column followed by different letters are significantly different ($p < 0.05$).

Table 6

Textural values for triticale bread with light brewers' spent sourdough

Samples	Hardness (N)	Adhesivity (N·s)	Coeshiviness (dimensionless)	Resilience (dimensionless)	Chewiness (N)
Ingen 40	21.25± 0.14 [a]	14.61± 0.04 [a]	0.719± 0.013 [f]	0.380± 0.002 [e]	15.28± 0.08 [a]
Ingen 40_10BSF	41.74± 0.21 [c]	32.94± 0.05 [c]	0.719± 0.009 [f]	0.403± 0.001 [f]	29.99± 0.01 [e]
Ingen 40_17.5BSF	49.53± 0.16 [e]	43.57± 0.08 [f]	0.733± 0.015 [g]	0.294± 0.002 [c]	36.30± 0.06 [h]
Costel	35.55± 0.14 [b]	31.61± 0.07 [c]	0.575± 0.005 [a]	0.276± 0.005 [b]	20.44± 0.11 [b]
Costel 10BSF	44.83± 0.09 [d]	34.85± 0.11 [d]	0.580± 0.0 [a]	0.290± 0.007 [c]	26.01± 0.01 [d]
Costel 17.5BSF	52.43± 0.18 [f]	44.25± 0.08 [f]	0.680± 0.0 [e]	0.381± 0.002 [e]	35.69± 0.04 [h]
Fanica	35.95± 0.12 [b]	25.64± 0.13 [f]	0.613± 0.005 [b]	0.306± 0.001 [c,d]	22.05± 0.09 [c]
Fanica 10BSF	50.98± 0.01 [e]	39.66± 0.07 [e]	0.633± 0.004 [c]	0.329± 0.003 [d]	32.27± 0.07 [f]
Fanica 17.5BSF	53.14± 0.07 [f]	38.43± 0.09 [e]	0.654± 0.005 [d]	0.221± 0.003 [a]	34.73± 0.04 [g]

[a–h], mean values (n = 3) in the same column followed by different letters are significantly different ($p < 0.05$).

The adhesivity values increase for the bread samples in which light brewers' spent sourdough has been incorporated. This effect may be due to the reduction of the water absorption capacity in the dough recipe, which may contribute to a stickier bread crumb.

Cohesiveness is a measure of the bread ability to maintain its structural integrity when it is subjected to deformation or breaking forces (e.g. during chewing). A decrease of these values by BSF addition in triticale flour indicates that bread sample become more crumbly or fragile probably due to a less gluten content from the samples (Curti et al., 2014). At high amount of BSF addition in triticale flour the resilience values decreased for Ingen 40 and Fanica variety. However, for the Costel variety the resilience value increase. An increase in bread resilience indicate that the bread is bouncier and more elastic and a decrease indicates that bread samples will slowly recovers when is subject to a small deformation. This may be related to the gluten content from the samples which may be in a higher or a less amount depending on the triticale variety used in bread recipe. Chewiness values increase for bread samples with BSF incorporated in their recipe. This indicates that the bread will requires more effort to bite and swallow probably due to the denser crumb by BSF addition in dough recipe (Huang et al., 2024).

Conclusions

Using triticale wholemeal flour can lead to the production of good-quality bread. The addition of sourdough from light brewer's spent grain flour contributes to increasing the biological value of bakery products due to its rich composition, including amino acids, dietary fiber, mineral substances, and bioactive compounds, while also valorising agro-food waste from the beer industry.

Light brewer's spent grain sourdough (BSF) significantly affects the rheological properties of triticale dough during mixing and pasting, leading to decreased water absorption, dough stability, dough development time, and Mixolab torques C2 and C3, while C4 and C5 show variability depending on the triticale variety and the level of BSF incorporation. The addition of brewer's spent grain sourdough reduces dough viscoelasticity by lowering G′ and G″ values, although elastic properties remain dominant, as indicated by tan δ values below 1 for all samples, and it weakens dough during extension by decreasing tenacity and baking strength.

During fermentation, brewer's spent grain sourdough has a positive effect on dough rheology by increasing H'm (maximum height of gaseous production), VT (total CO_2 volume production), and VR (volume of the gas retained in the dough at the end of the test) values, while CR (retention coefficient) values above 90% indicate the potential to obtain good-quality bread. Additionally, the significant decrease in falling number values suggests increased α-amylase In terms of bread quality, BSF addition significantly increases acidity and textural parameters such as hardness, adhesiveness, cohesiveness, and chewiness, while reducing loaf volume, porosity, and elasticity. It also results in a darker crumb and crust color. Sensory characteristics are influenced by both formulation and processing, leading to a slightly sweet taste, malt-like aroma, and characteristic cereal notes. Overall, the results indicate that supplementation with 10% brewer's spent grain sourdough produces triticale bread with very good sensory quality.

Acknowledgment. This work was supported by a grant from the Ministry of Research, Innovation and Digitization, CNCS-UEFISCDI, project number PN-IV-P8-8.3-ROMD-2023-0078, within PNCDI IV.

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Cite:

UFJ Style

Rumeus I., Ropciuc I., Saitan O., Ghendov-Mosanu A., Bulgaru V., Leatamborg S., Lupascu G., Gabriela Codină G. (2026), Influence of surface treatment with high oleic sunflower oil and thyme essential oil on Kashkaval cheese quality, *Ukrainian Food Journal*, 15(1), pp. 79–94, https://doi.org/10.24263/2304-974X-2026-15-1-8

APA Style

Rumeus, I., Ropciuc, I., Saitan, O., Ghendov-Mosanu, A., Bulgaru, V., Leatamborg, S., Lupascu, G., & Codină, G. G. (2026). Light brewer's spent grain as a functional ingredient in sourdough triticale bread production. *Ukrainian Food Journal, 15*(1), 79–94. https://doi.org/10.24263/2304-974X-2026-15-1-8