Influence of conditions of extraction of brewer`s spent grain with wheat semolina on the structural mechanical properties of the received extrudates

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Abstract
Mixtures of brewer`s spent grain with wheat semolina in different ratios are extruded on a single screw extruder (Brabender 20DN) under different process parameters. A degree of expansion index and extrudates density were determined. The density of extrudates was found to be higher in samples in which the percentage of brewer`s spent grain is higher. There is a linear relationship between the degree of expansion and density of extruded brewer`s spentgrain and wheat semolina.

Introduction
Extrusion is a high-temperature, short-term treatment in which raw materials, usually in the form of powders, produce ready-to-eat foods. Subjecting the material to a high temperature for a short time has a beneficial effect on the destruction of microorganisms and the destruction of heat-labile antifood factors.
Therefore, the initial properties of the material are completely changed after expansion and the end product has different structural-mechanical and chemical properties.
Extruded products are considered highly potent and stable for storage due to gelatinization of starch, denaturation of proteins, degradation of the trypsin and pepsin inhibitors and destruction of the enzyme systems of the raw materials.
The following factors influence the extrusion of the foodstuff: material composition and particle size; speed of rotation of the extruder; moisture content of the material fed for extrusion; template of the extruder die; die diameter and temperature of the mixing zone of the extruder.
The main raw materials for extrusion are starch-based: grain products obtained from wheat, maize and rice, potato starch and granules or dried potato flakes. Other cereal products obtained from rye, barley, oats and buckwheat are used less, especially for the purpose of nutrient enrichment, improvement in taste or functional characteristics of extrudates.
In the processing of brewer`s spent grain (waste product from the brewing industry), cheap products with prebiotic effect can be obtained by extrusion. In addition, the recovery of waste products from the food industry would solve a number of ecological and economic problems. The technology used is highly efficient and is practicable for all enterprises in the food processing industry.
The purpose of our studies is to determine the influence of the extrusion conditions of malt bran mixed with wheat semolina on the structural and mechanical properties of the extrudates obtained therefrom.

Materials and methods

The bran is obtained by grinding malts in a Corona hand mill and screening through sieves to produce particles with a mean diameter of 0.5 mm.
Malt bran is mixed with wheat semolina in different ratios according to the plan of the experiment. Destilled water is added to the samples to achieve the desired humidity (Table 1), then homogenized and stored for 24 hours at 5 ° C in closed polyethylene bags to equalize the moisture content of the material. Prior to extrusion, the samples are tempered.
To obtain the extrudates is used single screw extruder Brabender 20DN (Germany). During the trials the screw speed rotation is 70 rpm. The temperatures of the first and second zone are fixed respectively at 150 and 160ºC. The temperature of matrix and screw speed rotation vary depending on the plan of the experiment.

Table 1: Experiment plan in natural and encoded mode

№	Independent variables in encoded form				Independent variables in natural form			
	X_1 (C, %)	X_2 (W, %)	X_3 (n, rpm)	X_4 (Tm, ºC)	X_1 (C, %)	X_2 (W, %)	X_3 (n, rpm)	X_4 (Tm, ºC)
1	-1	-1	-1	-1	20	20	150	140
2	+1	-1	-1	-1	40	20	150	140
3	-1	+1	-1	-1	20	26	150	140
4	+1	+1	-1	-1	40	26	150	140
5	-1	-1	+1	-1	20	20	210	140
6	+1	-1	+1	-1	40	20	210	140
7	-1	+1	+1	-1	20	26	210	140
8	+1	+1	+1	-1	40	26	210	140
9	-1	-1	-1	+1	20	20	150	160
10	+1	-1	-1	+1	40	20	150	160
11	-1	+1	-1	+1	20	26	150	160
12	+1	+1	-1	+1	40	26	150	160
13	-1	-1	+1	+1	20	20	210	160
14	+1	-1	+1	+1	40	20	210	160
15	-1	+1	+1	+1	20	26	210	160
16	+1	+1	+1	+1	40	26	210	160
17	-2	0	0	0	10	23	180	150
18	+2	0	0	0	50	23	180	150
19	0	-2	0	0	30	17	180	150
20	0	+2	0	0	30	29	180	150
21	0	0	-2	0	30	23	120	150
22	0	0	+2	0	30	23	240	150
23	0	0	0	-2	30	23	180	130
24	0	0	0	+2	30	23	180	170
25	0	0	0	0	30	23	180	150
26	0	0	0	0	30	23	180	150
27	0	0	0	0	30	23	180	150

X1 – brewer`s spent grain content (C, %), X2 – moisture of the material (W, %), X3 – screw speed (n, rpm), X4 – temperature of the matrix (Tm, °C).

Sectional expansion index (%):

$$SEI = \frac{D_e}{D_o}.100\,,\ \%$$

De – average diameter from ten samples of extrudates, mm
Do – die diameter, mm

Density of extrudates (g/cm^3):

$$\rho = \frac{M(1-\frac{W}{100})}{V - M\frac{W}{100}}\ ,\ \ g/cm^3$$

M – weight of the sample, g
V – volume of the sample, cm^3
W – moisture of the sample, %

It is assumed that the shape of the extrudates is approaching cylindrical, measuring the average diameter of 10 pieces extrudates of the same length from different points of the experiment and calculate the volume.
In order to determine the influence of brewer`s spent grain content - X1, the moisture of the material - X2, screw speed - X3 and the temperature of the matrix - X4 on the dependent variables (SEI and p), the surface of the reflection method was applied using rotatable central composite plan.

Results and discussion
Sectional expansion index and density of the extrudates are important parameters determining the extrusion process. These are parameters that characterize the structural and mechanical changes that occur as a result of the extrusion treatment of the material and can be controlled by changing the type and origin of the ingredients used as well as by changing the process conditions in the extruder.

1. Sectional expansion index

The values of the degree of expansion index in the extrusion of a mixture of brewer`s spent grain with wheat semolina range from 92 to 245% (Table 2).

Table 2: Sectional expansion index

№	SEI, %	№	SEI, %	№	SEI, %
1	225	**10**	130	**19**	245
2	152	**11**	133	**20**	111
3	202	**12**	92	**21**	113
4	111	**13**	193	**22**	149
5	203	**14**	177	**23**	220
6	146	**15**	131	**24**	99
7	181	**16**	115	**25**	113
8	95	**17**	242	**26**	112
9	208	**18**	224	**27**	113

The coefficients of the regression equation for the degree of expansion index obtained by processing the test results are given in Table 3.

Table 3: Regression coefficients of variants for the degree of expansion index and density of the extrudates

Variables	**SEI coefficients**	**Density coefficients**
Constant	3995,76	23,882
X_1	-36,3542*	-0,0571*
X_2	-41,412*	-0,3917*
X_3	-4,4931	-0,0127
X_4	-29,5083*	-0,2349
X_1X_1	0,2683*	0,0009*
X_1X_2	-0,0208	0,0006
X_1X_3	0,0225	-0,00002
X_1X_4	0,0975	0,00003
X_2X_2	1,4537	0,0069*
X_2X_3	-0,0139	0,0001
X_2X_4	-0,2083	0,0004
X_3X_3	0,0015	0,0001*
X_3X_4	0,0246	-0,0001
X_4X_4	0,0846	0,0008*

X1 – brewer`s spent grain contents (%), X2 – moisture of the material (%),
X3 – screw speed rotation (rpm), X4 – temperature of the matrix (°C)
* Significant coefficients of regression at P<0,05.

It has been found that the moisture content of the material is the main factor influencing expansion. Increased moisture content during extrusion can reduce the elasticity of the dough by plasticizing the molten mass, resulting in a reduction in specific mechanical energy and hence in a reduction in gelatinization and a reduction in extrudate expansion (Ding et al., 2006) .
A graphical representation of the change in the degree of expansion depending on the moisture content of the material and the temperature of the matrix is given in fig. 1. When the moisture content of the material and the temperature of the matrix increase simultaneously, the expansion decreases.

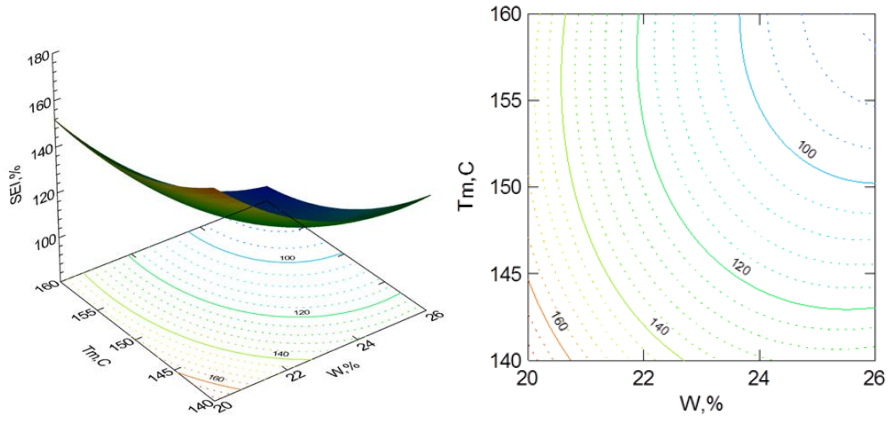

Fig 1: Change of expansion index (SEI,%) depending on moisture content (W,%) and temperature of the matrix (Tm, ºC) for 30% brewer`s spent grain content and 180 rpm screw speed rotation.

2. Density

Extrudate density values range from 0.151 to 0.71 g / cm3 (Table 4) and the density regression coefficients obtained by processing the test results are given in Table 3.

Table 4: Density

№	ρ, g/cm³	№	ρ, g/cm³	№	ρ, g/cm³
1	0,307	**10**	0,384	**19**	0,361
2	0,375	**11**	0,408	**20**	0,466
3	0,353	**12**	0,710	**21**	0,448
4	0,506	**13**	0,255	**22**	0,301
5	0,299	**14**	0,424	**23**	0,482
6	0,377	**15**	0,508	**24**	0,487
7	0,435	**16**	0,512	**25**	0,155
8	0,546	**17**	0,334	**26**	0,151
9	0,404	**18**	0,685	**27**	0,152

Between the density and the degree of expansion, there is a disproportionate dependence, ie. extrudates with less expansion have a higher bulk density (Ding et al., 2006, Lazou & Krokida, 2010, Singh et al., 2007). Generally, the results obtained show that the density increases with increasing the moisture content of the raw materials (Figure 2). Increased moisture content in the material would alter the macromolecular structure of molten mass, reducing its elasticity, thereby reducing expansion and helping to form more compact extrudates (Lazou & Krokida, 2010).

Increased density of extrudates with an increase in brewer`s spent grain content in the mixtures may be due to the increased content of dietary fiber in the raw material, leading to cell wall rupture to fully expand the molten mass (Lue et al., 1991).

The results obtained show that the extrudate density increases about 2 times with an increase in the brewer`s spent grain content in the mixture of 10 to 50% at a mold temperature of 150 ° C, a screw rotation speed of 180 rpm and a moisture content of 23%.

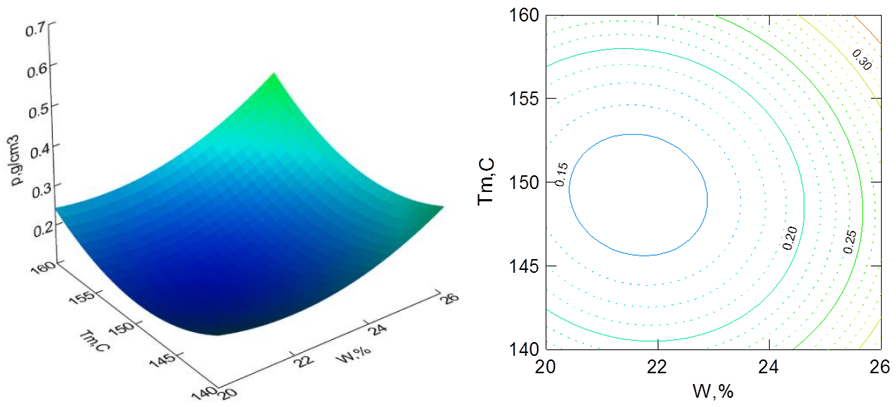

Fig. 2: Change of density (ρ, g / cm3) depending on the moisture content (W,%) and the temperature of the matrix (Tm,ºC) with brewer`s spent grain content 30% and screw speed 180rpm.

Conclusion

Changes in the degree of expansion and extrusion density of a mixture of brewer`s spent grain with wheat semolina were studied. The moisture content of the material, the brewer`s spent grain content in the extrusion mixture and the temperature of the matrix significantly influence the expansion and density of the resulting extrudates. The values of the degree of expansion index of brewer`s spent grain extrudates with wheat semolina range from 92 to 245% and for the density from 0.151 to 0.71 g / cm3.

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