

Rye – the nutritional and technological evaluation in Czech cereal technology – A review: Grain and flours

MARCELA SLUKOVÁ*, LUCIE JURKANINOVÁ, IVAN ŠVEC, PAVEL SKŘIVAN

*Department of Carbohydrates and Cereals, Faculty of Food and Biochemical Technology,
University of Chemistry and Technology Prague, Prague, Czech Republic*

*Corresponding author: Marcela.Slukova@vscht.cz

Citation: Sluková M., Jurkaninová L., Švec I., Skřivan P. (2021): Rye – the nutritional and technological evaluation in Czech cereal technology – A review: Grain and flours. *Czech J. Food. Sci.*, 39: 03–08.

Abstract: Rye is a later cereal compared to wheat and barley. The main use of rye in human nutrition consists in the processing of grain to flour (dark and wholemeal) and in the baking industries in sourdough and bread making. During the last fifty years, there has been a decline in the consumption of rye in the Czech Republic. Rye is a nutritionally interesting cereal due to its high fibre content. The part of the review presents the development of consumption of rye and rye products, nutritional significance of rye products, changes in the properties and content of rye grain components during processing with a focus on the evaluation of the effect of milling on components and microstructure of rye flour.

Keywords: cereal arabinoxylans; microstructure of flour; milling process; rye fibre; wholemeal rye flour

Production, consumption and processing of rye

Rye (*Secale cereale* L.) was grown in Europe a thousand years BC, when it is genetically closely related to wheat and barley (the tribe Triticeae) (Arendt and Zannini 2013; Wrigley and Bushuk 2017). However, rye is harder than wheat and barley. Rye was introduced into Europe by the arrival of Germans, and particularly of Slavs. This is the reason why rye has traditionally been cultivated in Central, Northern and Eastern Europe (Petr 2008; Delcour and Hoseney 2010; Poutanen 2014).

Rye production accounts for less than 1% of the total global cereal production; compared to wheat the world rye production is only 3% (Arendt and Zannini 2013). In the regions where rye is an important cereal, or where it was a major bread making cereal in the past like in Germany, Poland, Russia, Belorussia, Ukraine and also in Bohemia and Slovakia, dark sourdough rye bread has been made in different re-

gional varieties along with other rye products (Wrigley and Bushuk 2017; Strassner 2020).

Rye flour is the basic ingredient of the bread recipe when flour is not used in raw form but for the preparation of rye sourdough that is added to dough (Gobbetti et al. 2014; Šedivý and Albrecht 2014; Brandt 2019).

As mentioned above, rye is cultivated also in the Czech Republic, where its use as food is mainly associated with traditional sourdough mixed 'rye-wheat' or 'wheat-rye' bread (Šedivý and Albrecht 2014). In the former bread the rye to wheat flour ratio is higher than 50%, in the latter bread wheat flour prevails but in both breads the sourdough is made of rye flour only. Very similar kinds of bread are produced in Austria, Slovakia and south-eastern Germany (Strassner 2020). A wheat and rye flour mix has two significant advantages. It can provide bread with attractive sensory properties whose structure is also

built of viscoelastic wheat gluten that is not formed in rye flour (Wrigley and Bushuk 2017).

Rye is used for the production of crisp breads (Knäckebröt) (Camire 2002; Arendt and Zannini 2013), flakes and cereal snacks (Perdon et al. 2020).

In the Czech Republic, similarly, like in other countries where rye has been traditionally grown and consumed, rye consumption was substantially reduced, while wheat consumption has increased in the last decades (in fact since the mid-20th century) (Petr 2008; CZSO 2020). The Czech Republic is one of the countries that have abandoned their tradition to the largest extent in the last 50 years. Rye production has been progressively and constantly decreasing in the Czech Republic since 1961 (since the year when the systematic recording of FAOSTAT data started). Annual rye production was around 994 000 t in 1961 while in the seventies and eighties its production decreased almost to half of this volume. In 2000–2008 rye production was a fifth of the production in 1961 and in 2016 a tenth (production of 104 000 t). It must be noted that rye bread in comparison with wheat bread and pastry brings evident health benefits.

Health aspects of rye

The intake of wholegrain cereal products is associated with a reduced risk of development of many civilization diseases and health disorders: a reduction in the risk of type 2 diabetes in adults, induction of the feeling of satiety and a decrease in the inclination to overeat (Kamal-Eldin et al. 2007; Isaksson 2014 and others). Some cereal fibres influence the conversion of cholesterol to bile acids in the liver; it can improve the large intestine function and decrease the concentration of some molecular biomarkers which increase the colorectal cancer risk. Some mechanisms behind the beneficial effects of fibre, especially with regard to phenolic compounds, consist in sorption and reduction of toxic substances from the intestinal wall and their elimination by faeces (Bach Knudsen and Lærke 2014). The Commission Regulation (EU) No. 432/2012 lays down the admissible health claims and conditions of use of the claims specifically for rye fibre: 'Rye fibre contributes to normal bowel function'. This claim should be applicable only to foods with high fibre content as set down in an appendix to Regulation (EC) No. 1924/2006.

The Czech Republic is a country with a high frequency of many civilization diseases, where the increased intake of cereal fibre and products of lactic acid fermentations occurring in traditional rye sourdough bread can have preventive effects (Kohout et al.

2010). As mentioned above, the proportion of rye and traditional bread in Czech food has substantially decreased. Therefore, it is essential to constantly accentuate advantages of the consumption of rye, rye bread and baked products and to support them by scientific arguments.

We shall discuss in detail two aspects playing a crucial role in this context: specific composition of rye grain and specificity of the milling process of rye.

Chemical composition and changes during rye processing

Chemical composition of rye grain is related to rye variety, climatic and cultivation conditions, soil quality, etc. (Delcour and Hoseney 2010; Wrigley and Bushuk 2017). The basic composition of rye grain is similar to the composition of other cereals. Starch is the main component of rye grain and flour. The shape of rye starch granules (lenticular and spherical) and their size (A-type starch fraction 20–35 µm, B-type starch fraction 5–10 µm) are similar to wheat starch granules. There are cavities or fissures in the central part of larger rye starch granules. The temperature range of rye starch gelatinization is lower than in wheat starch. Starch granules of rye flour show a higher level of enzymatic and mechanical damage compared to wheat starch. Rye endosperm and flours contain relatively less starch and proteins, but more fibre than wheat (Cardoso et al. 2019).

The outer layer of endosperm, the aleurone layer, is rich in bioactive compounds such as minerals (phosphorus, potassium, iron, magnesium, zinc), vitamins (B vitamins especially thiamine, riboflavin and niacin, and vitamin E) and phenolic compounds (polyphenols and phenolic acids), lignans, alkylresorcinols, sterols and stanols (McKevith 2004; Aura 2014). Bioactive cereal compounds such as phenolic compounds (in particular flavonoids, isoflavones, and flavanones) are secondary metabolites of the plants (Khan et al. 2020). These compounds have protective health-promoting effects (prevention of cardiovascular diseases, inflammation, glucose intolerance and obesity). Phenolic acids in rye are hydroxylated derivatives of benzoic and cinnamic acids. Lignans can be found as a part of lignin polymer or in free form as glycosides. Lignans are characterized by oxysubstitutions on aromatic rings, they contain cinnamic acid residues. 5-*n*-Alkylresorcinols (i.e. 1,3-dihydroxy-5-*n*-alkylphenols) are amphiphilic compounds with alkyl chains in the range of C15 to C25. Phytosterols chemically belong to the group

<https://doi.org/10.17221/203/2020-CJFS>

of steroids; the saturated derivatives of sterols are referred to as stanols.

The fibre content in food can change during food processing, either during bread making (baking) or extrusion (Andersson et al. 2009; Mihhalevski et al. 2013; Comino et al. 2016, and others). Common changes include an increase in the resistant starch content in extruded or deep-frozen rye products and an increased content of soluble β -glucan in extruded products (Birkett 2007). A reduced content of soluble fibres such as fructans and β -glucans was determined in sourdough and ripening dough (Sozer and Poutanen 2013).

In the preparation of rye dough the rye protein does not make a viscoelastic structure of dough like in wheat. However the cell wall polysaccharides have a great influence on rheological properties of rye dough and rye bread texture (Delcour and Hoseney 2010).

Wholemeal rye flour contains in dry matter 56–70% (w/w) of starch, 8–13% of proteins, 2–3% of lipids, 2% of ash and 15–21% of total fibre (Kamal-Eldin et al. 2007). Rye flour with a nearly 100% extraction rate is produced in Finland and Denmark. In Sweden and Norway, similarly, like in Germany or in the Czech Republic, rye flour with about 80% extraction rate is most commonly used (Strassner 2020).

Fibre content in the rye grain is highest among common cereals (Andersson et al. 2014). Arabinoxylans (Arabinoxylans) (both water-extractable and water-unextractable ones) are the most important and typical constituent of rye fibre (Andersson et al. 2009). Other fibre constituents are cellulose, fructans, mixed-linkage β -glucans and resistant starch.

Arabinoxylans along with proteins contribute to the water-binding capacity in rye dough to the largest extent since arabinoxylans bind water much more strongly than proteins. Arabinoxylans, especially water-soluble ones, contribute to higher binding capacity of rye flour and higher dough viscosity (Delcour and Hoseney 2010; Cardoso et al. 2019). Rye arabinoxylans, bound with proteins through ferulic acid to the form of high-molecular-weight glycoproteins, create the rye dough and breadcrumb structure. This gel-like structure also causes slower starch retrogradation and hence slower aging of rye-based products. The high-molecular-weight rye proteins are not able to create a three-dimensional flexible network, do not provide a porous and supple structure of rye breadcrumb and a high volume of the product in comparison with wheat proteins (gliadins and glutenins).

Rye dietary fibre and proteins (especially rye albumins and globulins) are essential for human nutrition

and are responsible for the beneficial health effects of rye bread with lower glycaemic load (Lappi et al. 2010; Rakha et al. 2013, and others). The effects of rye fibre on health were studied in relation to the behaviour of its constituents in the human digestive tract (Bach Knudsen and Lærke 2014). Water-soluble arabinoxylans and β -glucans are partly digested in the small intestine and heavily degraded in the large intestine (Peredo-Lovillo et al. 2020). Rye fructans and fructooligosaccharides behave like prebiotics in the large intestine and are fully fermented to short-chain fatty acids in the large intestine (Andersson et al. 2014). However, insoluble arabinoxylans, cellulose and lignin are resistant to microbial degradation in the gut.

Mill processing and its impact on the flour microstructure and components

In human nutrition, rye is mainly used as a raw material in the milling industry while white (light) and especially dark bread flours are products of the standard milling process of rye (Godon and Willm 1998; McKeivith 2004; Andersson et al. 2014). The ash content of rye flour produced in Central Europe ranges from 0.5% for white flour to 1.5% for very dark flour. Wholemeal rye flours (ash content up to 2.0%, w/w in dry matter) are also produced. The T 930 bread flour with ash content up to 1.1% is the most common and most frequently used rye flour in the Czech Republic. Besides flour, rye flakes or differently hydrothermally treated and fermented or roasted grains are also produced. These products are mostly used in particular types of bread and cereals.

The most commonly used method of rye milling is based on the same principle as wheat milling (McKeivith 2004). It is a process of repeated steps, so called passages, consisting of disintegration and separation. Grains are wetted and tempered before entering the milling process. The purpose of these operations is to separate outer layers and germs and to extract the endosperm. Whereas in wheat the separation of the endosperm from outer layers is feasible with high efficiency, in rye it is not possible to this extent. The rye grains are thinner and more elongated than wheat and the outer layers are more strongly attached to the endosperm (Delcour and Hoseney 2010). The milling process of rye is less friendly (more intensive) and consists of a lower number of passages compared to wheat.

An example of such a process is the technology of finely granulated wholemeal rye flour production that is currently tested successfully in the Czech Republic in a special type of mill consisting of a special

impact mill with the vertical shaft of rotation (Skřivan et al. 2017). In the mill chamber the material moves upward carried with the stream of air; disintegration is performed by rotating steel segments ('hammers') in several rows above each other and specially adjusted inner housing of the mill. A screen with adjustable mesh size is affixed to the upper side of the mill drum and the material moves in the stream of air through the disintegration space until the particles pass through the chosen screen. It allows much finer disintegration (granulation) of the outer layers without greater damage to starch granules of the endosperm compared to the standard milling process. The resulting very fine wholemeal flours are easier to process compared to common wholemeal flours, and subsequently the bread has better sensory parameters (Drakos et al. 2017; Skřivan et al. 2017).

In the Czech Republic two kinds of rye flour have traditionally been produced: white (light) rye flour with 0.50–0.65% content of ash in dry matter, and particularly, in the last decades when its production has become quite dominant, bread rye flour with ash content up to 1.10%. The colour of white rye flour, whose extraction rate is 10–30%, is near to the colour of wheat flours. Bread flour (previously classified as T 930) has a typical greyish colour and its extraction rate differs in relation to the level of white flour production, most frequently being in the range of 60–70%. The total extraction rate of rye flours in the Czech Republic ranges from 75 to 80%. Especially bread rye flour contains a significant proportion of arabinoxylans (up to 10%).

Rye grains generally have a higher activity of amylases than wheat grains, and therefore the starch granules are usually strongly damaged by enzyme activities (Delcour and Hoskeney 2010). Besides amylases, the activity of proteases and xylanases is also higher compared to wheat. The higher enzyme activity of amylases plays its crucial role in the formation of rye sourdough. The starch granules that were thermally and mechanically damaged during milling are more susceptible to enzymatic hydrolysis. The level of starch damage determines the intensity of fermentation process, and at the same time along with the high content of arabinoxylans it also determines the character of rye dough and breadcrumb (Gänzle 2014).

The degree of starch granule damage influences not only flour behaviour during sourdough ripening and dough formation but also an important nutritional aspect. Greater damage to starch granules causes the fast resorption of starch (glucose) into blood, which can

moderately increase the glycaemic index (GI). However, this increase in GI is fully compensated when darker flours with high fibre contents, mainly wholemeal rye flours, are used (Ludwig and Eckel 2002).

But the milling process when lighter flours are produced consists in more intensive removal of the grain outer coating in the form of brans. This results in higher GI values and is negatively reflected in other nutritional characteristics like a decrease in the content of lysine which is generally a limiting essential amino acid in cereals, a decrease in the content of cereal fibre, minerals and other bioactive compounds (Andersson et al. 2014; Delcour and Hoskeney 2010).

CONCLUSION

Rye is a harder cereal compared to wheat. During the last twenty years, there has been a gradual decrease in rye production in the food industry in the Czech Republic. Rye and rye products are an important source of cereal fibre with proven health benefits. From a nutritional point of view rye is more valuable than wheat although rye also contains the protein called gluten that is unsuitable for people with celiac disease. However, rye is nutritionally beneficial for the population not suffering from gluten intolerance. During the processing of rye and rye flour, a number of physicochemical processes occurs which lead to changes in the composition, properties and availability of nutritionally and technologically important components. Changes affect water absorption of rye flour, structure and viscosity of dough, quality and yield, and glycaemic index of rye bread. Production of flour with higher content of fibre and/or wholemeal flour is a modern trend of milling processing of rye. Non-traditional, modified mill equipment is often used to produce wholemeal and dark rye flours with fine granulation. This modification allows easier bioavailability of rye fibre and other bioactive compounds, lower degree of starch damage and lower glycaemic index of the product and sufficient substrate for fermentation.

REFERENCES

- Andersson R., Fransson G., Tietjen M., Åman P. (2009): Content and molecular-weight distribution of dietary fiber components in whole-grain rye flour and bread. *Journal of Agricultural and Food Chemistry*, 57: 2004–2008.
- Andersson A.A.M., Rakha A., Andersson R., Åman P. (2014): Rye Dietary Fiber. In Poutanen K. and Åman P. (eds): *Rye and Health*. AACC Inc. St. Paul, Minnesota, USA: 25–41.

<https://doi.org/10.17221/203/2020-CJFS>

- Arendt E.K., Zannini E. (2013): Rye. In: Arendt E.K., Zannini E. (eds): *Cereal Grains for the Food and Beverage Industries*. Woodhead Publishing Ltd. Cambridge, United Kingdom: 220–242.
- Aura A.M. (2014): Phenolic Acids in Rye. In: Poutanen K., Åman P. (eds): *Rye and Health*. AACC Inc. St. Paul, Minnesota, USA: 110–117.
- Bach Knudsen K.E., Lærke H.N. (2014): The Influence of Rye Fiber on Gut Metabolism. In: Poutanen K. and Åman P. (eds): *Rye and Health*. AACC Inc. St. Paul, Minnesota, USA: 50–64.
- Birkett A.M. (2007): Resistant starch and health. In: Hamaker B.R. (ed.): *Technology of functional cereal products*. Woodhead Publishing Ltd. Cambridge, United Kingdom: 70–78.
- Brandt M.J. (2019): Industrial production of sourdoughs for the baking branch – An overview. *International Journal of Food Microbiology*, 302: 3–7.
- Camire M.E. (2002): Extrusion cooking. In: Henry C.J.K., Chapman C. (eds): *The nutrition handbook for food processors*. Woodhead Publishing Ltd. Cambridge, United Kingdom: 314–321.
- Cardoso R.V.C., Fernandes Â., Heleno S.A., Rodrigues P., González-Paramás A.M., Barros L., Ferreira I.C.F.R. (2019): Physicochemical characterization and microbiology of wheat and rye flours. *Food Chemistry* 280: 123–129.
- Comino P., Collins H., Lahnstein J., Gidley M.J. (2016): Effects of diverse food processing conditions on the structure and solubility of wheat, barley and rye endosperm dietary fibre. *Journal of Food Engineering*, 169: 228–237.
- CZSO (2020): Czech Statistical Office. Available at <https://www.czso.cz/csu/czso/home> (accessed 25 May 2020).
- Delcour J.A., Hoseney R.C. (2010): *Principles of Cereal Science and Technology*. 3rd Ed. AACC Inc. St. Paul, Minnesota, USA: 70–78, 115–122, 144–148, 217–225.
- Drakos A., Kyriakakis G., Evageliou V., Protonotariou S., Mandala I., Ritzoulis Ch. (2017): Influence of jet milling and particle size on the composition, physicochemical and mechanical properties of barley and rye flours. *Food Chemistry*, 215: 326–332.
- Gänzle M. (2014): BREAD, Sourdough bread. Reference module in food science. In: Batt C., Robinson R. (eds): *Encyclopedia of Food Microbiology*. Academic Press: 309–315.
- Gobbetti M., Rizzello C.G., Di Cango R., De Angelis M. (2014): How the sourdough may affect the functional features of leavened baked goods. *Food Microbiology*, 37: 30–40.
- Godon B., Willm C. (1994): *Primary Cereal Processing: A Comprehensive Sourcebook*. Wiley-VCH Publishers, Inc.: 78–90, 123–155.
- Isaksson H. (2014): Satiating Effects of Rye Foods. In: Poutanen K., Åman P. (eds): *Rye and Health*. AACC Inc. St. Paul, Minnesota, USA: 189–201.
- Kamal-Eldin A., Aman P., Zhang J.X., Bach Knudsen K.E., Poutanen K. (2007): Rye bread and other rye products. In: Hamaker B.R. (ed.): *Technology of Functional Cereal Products*. Woodhead Publishing: 233–260.
- Khan M.K., Chemat F., Sattar S., Imran M. (2020): Extraction of Bioactive Molecules: Conventional Versus Novel Methods. In: Suleria H.A.R., Barrow C. (eds): *Bioactive Compounds from Plant Origin*. Apple Academic Press, Inc.: 3–5.
- Kohout P., Rušavý Z., Šerclová Z. (2010): Chosen chapters from the clinical nutrition I. Volume II (Vybrané kapitoly z klinické výživy I. Svazek II). Forsapi: 15–25. (in Czech)
- Lappi J., Selinheimo E., Schwab U., Katina K., Lehtinen P., Mykkänen H., Kolehmainen M., Poutanen K. (2010): Sourdough fermentation of wholemeal wheat bread increases solubility of arabinoxylan and protein and decreases postprandial glucose and insulin responses. *Journal of Cereal Science*, 51: 152–158.
- Ludwig E., Eckel R. (2002): The glycemic index at 20 y. *American Journal of Clinical Nutrition*, 76: 264S–265S.
- McKevith B. (2004): Nutritional aspects of cereals. *Nutrition Bulletin*, 29: 111–142.
- Mihhalevski A., Nisamedtinov I., Hälvin K., Ošeka A., Paalme T. (2013): Stability of B-complex vitamins and dietary fiber during rye sourdough bread production. *Journal of Cereal Science*, 57: 30–36.
- Perdon A.A., Schonauer S.L., Poutanen K. (2020): *Breakfast Cereals and How They Are Made: Raw Materials, Processing, and Production*. AACC Inc. St. Paul, Minnesota, USA: 28–35.
- Peredo-Lovillo A., Romero-Luna H.E., Jiménez-Fernández M. (2020): Health promoting microbial metabolites produced by gut microbiota after prebiotics metabolism. *Food Research International*, 136: Article 109473.
- Petr J. (2008): *Rye and Triticale (Žito a tritikale)*. Prague, Profi Press: 13–16. (in Czech)
- Poutanen K. (2014): Rye and Rye Bread – An Important Part of the North European Bread Basket. In: Poutanen K., Åman P. (eds): *Rye and Health*. AACC Inc. St. Paul, Minnesota, USA: 1–5.
- Rakha A., Åman P., Andersson R. (2013): Fibre-enriched and wholegrain breads. In: Delcour J.A., Poutanen K. (eds): *Improving quality*. Woodhead Publishing Ltd. Cambridge, United Kingdom: 211–235.
- Sozer N., Poutanen K. (2013): Fibre in extruded products. In: Delcour J.A., Poutanen K. (eds): *Fibre-Rich and Wholegrain Foods: Improving Quality*. Woodhead Publishing Ltd. Cambridge, United Kingdom: 256–272.
- Skřivan P., Sluková M., Vaculová K., Kozelková T., Perner D. (2017): Characterization and comparison of whole grain flours with different damaged starch and fibre content. In: Čopíková J., Šárka E. (eds): *Proceeding of the 13th Interna-*

<https://doi.org/10.17221/203/2020-CJFS>

- tional Conference on Polysaccharides-Glycoscience, 8–10 November, 2017, Prague, Czech Republic: 221–224.
- Strassner C. (2020): Food, nutrition and health in Germany. In Braun S., Zübert Ch., Argyropoulos D., Hebrard F.J.C. (eds): Nutritional and Health Aspects of Food in Western Europe. Academic Press: 133–158.
- Šedivý P., Albrecht J. (2014): Bakery Technology II: Bread production (Pekařská technologie II.: Výroba chleba). Pekař a Cukrář s.r.o., Prague: 27–51. (in Czech)
- Wrigley C., Bushuk W. (2017): Cereal Grains. Assessing and Managing Quality. In Wrigley C., Batey I., Miskelly D. (eds): Rye: Grain-Quality Characteristics and Management of Quality Requirements. Woodhead Publishing Ltd. Cambridge, United Kingdom: 153–178.

Received: August 12, 2020

Accepted: January 19, 2021