The productivity, quality and bread-making properties of organically and conventionally grown winter rye

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Abstract
Rye in combination with wheat is the major bread grain in northern Europe. Consuming rye whole grain products provides a rich source of dietary fibre as well as several bioactive compounds with potentially positive health implications. Due to limited research data concerning rye growing under different cultivation systems, there is also a lack of information on the influence of these systems on the quality properties of rye breads. The goal of the research was to compare the responses of rye to the conditions of organic and conventional management. The analysed properties included grain yield and quality, followed by the quality properties of whole grain flour, and ending with those of the end-product. Baking tests were carried out by using sourdough fermentation, and the pasting behaviours of rye flours were assessed using the Brabender Viscograph. Rye was grown on a sandy loam Albic Stagnic Luvisol (LVab-st) in a five-year crop rotation. Red clover was ploughed into the soil as green manure before rye sowing. For the organic treatment, no agrichemicals were used. For the conventional treatment, mineral fertilizers (N83P30K75 kg ha−1 in total) and herbicides were applied. The results of this seven-year experiment showed that the grain yield by the organic treatment was 64% of that obtained by the conventional treatment. For the conventional treatment, the protein content was significantly (P < 0.05) higher than for the organic treatment. An inverse correlation (r = −0.596) was determined between protein and starch contents of rye whole grain flour. Although several differences occurred in the flour properties and fluctuations in the viscograms for the organic and conventional treatments, no significant differences in the properties of breads were established between the treatments. Consequently, the breads baked by using whole grain flour derived from organically and conventionally cultivated rye were practically of the same quality.

Keywords: falling number, grain yield, loaf volume, protein, sourdough, starch.

Introduction
The interest in healthy food is increasing worldwide, bringing about also a growth in consumer demand for fibre-rich products. Products containing rye are the best representatives of this food group. As rye is mainly used in the form of whole grain products, it serves as a rich source of dietary fibre as well as of several classes of phytochemicals, bioactive compounds with potentially positive health implications (Poutanen et al., 2009; Åman et al., 2010; Bach Knudsen et al., 2009; Banu et al., 2011). Polysaccharides that are the constituents of cell walls in rye endosperm are very important for rheological and baking properties of rye bread (Åman et al., 2010). Water-extractable arabinoxylans have beneficial effects on the processability of the rye dough and the resulting bread as they increase the viscosity of the dough, improve bread crumb and volume, and delay starch retrogradation (Nowotna et al., 2006; Banu et al., 2011).

Wholemeal rye bread cannot be produced without a fermentation process. Sourdough, being a key element in traditional rye bread baking, is a mixture of flour and water with lactic acid bacteria and yeasts (Poutanen et al., 2009; Viiard et al., 2016). Sourdough contributes significantly to the dough processability, and to the flavour and texture of the bread. Also, it has been shown effective for the solution of minerals contained in bread cereals (Poutanen et al., 2009). The prolonged sourdough fermentation has been demonstrated to maintain the content of thiamine (B1) and nicotinamide (B3) during the rye bread baking (Martinez-Villaluenga et al., 2009; Poutanen et al., 2009; Mihhalevski et al., 2009; Banu et al., 2011).

Please use the following format when citing the article:
In 2007, the crop rotation in the present work was set according to the principles of organic farming, with no fertilizer and pesticides during the five-year crop rotation: for potato – N 60 P 60 K 120 kg ha\(^{-1}\), oats – N 72 P 18 K 36 kg ha\(^{-1}\), barley with undersown clover – N 48 P 12 K 24 kg ha\(^{-1}\). For the organic treatment, no fertilisers were used for any crop rotation.

Winter rye cultivar ‘Elvi’, seeding rate 450 seeds per 1 m\(^2\), was sown during the period between 28 August (2013) and 13 September (2008). For the conventional treatment, mineral N 15 P 30 K 75 kg ha\(^{-1}\), as complex fertilizer was applied during sowing. For rye, the following herbicides were applied: in 2008–2011 – Secator (a.i. amidosulfuron 100 g l\(^{-1}\), iodosulfuron-methyl-sodium 25 g l\(^{-1}\), rate 150 ml ha\(^{-1}\)), 2012 – Mustang Forte (a.i. florasulam 5 g l\(^{-1}\), aminopyralid 10 g l\(^{-1}\), 2.4-D 180 g l\(^{-1}\), 700 ml ha\(^{-1}\), 2013 – Tomigan 180 EC (a.i. fluroxypyr 180 g l\(^{-1}\), 500 ml ha\(^{-1}\) ) + Trimmer 50SG (a.i. methyl-tribenuron 500 g kg\(^{-1}\), 18 g ha\(^{-1}\)) and 2014 – Granstar Preemia 50SX (a.i. methyl-tribenuron 500 g kg\(^{-1}\), 15 g ha\(^{-1}\)) + Primus XL (a.i. fluoroxypr 100 g l\(^{-1}\), florasulam 5 g l\(^{-1}\), 700 ml ha\(^{-1}\)).

At the maturity stage, before combine-harvesting of rye, four replications of sheaves from a 1 m\(^2\) area were collected from the plots of both treatments. The ears were cut, and dried in laboratory conditions. After that, by simple random sampling, the representative rye grain samples (each about 5 kg) were collected from the plots of both treatments. The ears were threshed by hand and sorted through a 1.8 mm grain sieve (ISO 5223:1995 - Test sieves for cereals). The grain yield was quantified on 86% dry matter content. For both organic and conventional treatments, the grains of four replications were put together, and the composite grain samples for quality analyses were composed. For both treatments, matured rye on the 400 m\(^2\) plots was harvested by a John Deere combine in the last few days of July or in the first week of August. The rye yield was dried and sorted in the experimental drier of the Olustvere training farm, Estonia. After that, by simple random sampling, the representative rye grain samples (each about 5 kg) were composed for the rheological analyses and baking tests.

**Weather conditions.** The detailed data from the nearest Meteorological Station at Viljandi (58°22’ N, 25°35’ E) on the monthly (January to December) precipitation and air temperatures during the experimental years (2008–2014) have been presented in Järvan et al. (2017). Success in winter rye production is highly dependent on the weather conditions, especially during the winter months. During the seven-year period, the weather conditions were quite variable. In the winters of 2010–2011 and 2012–2013, the extraordinary severewintering conditions for rye plants prevailed and, because of this, a high number of plants perished through snow mould and/or other plant diseases.
In Estonia, the vegetation period for rye in the second year usually begins in the middle of April and the harvesting takes place at the end of July or in early August (Tupits, 2008). For this four-month period, the meteorological data (Table 1) indicate that the precipitation from the beginning of April to the end of July varied from 157 mm (2011) to 288 mm (2012). 2010 was a year characterized by below average (208 mm) and 2014 by above average (283 mm) rainfall during the main growth period. In 2008–2014, the average precipitation (April–July) reached 233 mm, and the average air temperature for this period was 13.0°C. Early springs of 2012 and 2013 were the coldest during the experimental years, which delayed the start of rye vegetation. The earliest spring during the experiment occurred in 2014, triggering rye growth already in March and allowing an earlier (4th April) application of the first dose of nitrogen. In July 2010, 2011 and 2014, extraordinarily high monthly average air temperatures (from 19.7°C to 22.4°C) prevailed. May and June of 2013 were unexpectedly warm, up to 3–4°C higher than the multi-annual average.

**Preparation of natural rye flour leaven (in 2008)**

<table>
<thead>
<tr>
<th>Month</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>52</td>
<td>17</td>
<td>35</td>
<td>11</td>
<td>53</td>
<td>44</td>
<td>15</td>
</tr>
<tr>
<td>May</td>
<td>22</td>
<td>17</td>
<td>53</td>
<td>58</td>
<td>62</td>
<td>75</td>
<td>88</td>
</tr>
<tr>
<td>June</td>
<td>119</td>
<td>91</td>
<td>77</td>
<td>22</td>
<td>81</td>
<td>21</td>
<td>108</td>
</tr>
<tr>
<td>July</td>
<td>48</td>
<td>136</td>
<td>43</td>
<td>66</td>
<td>92</td>
<td>51</td>
<td>72</td>
</tr>
<tr>
<td>Total</td>
<td>241</td>
<td>261</td>
<td>208</td>
<td>157</td>
<td>288</td>
<td>191</td>
<td>283</td>
</tr>
</tbody>
</table>

**Table 1.** Monthly total precipitation and average air temperatures from April to July, 2008–2014

<table>
<thead>
<tr>
<th>Month</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation mm</td>
<td>7.2</td>
<td>10.8</td>
<td>14.6</td>
<td>16.5</td>
<td>12.3</td>
</tr>
<tr>
<td>Temperature ºC</td>
<td>6.0</td>
<td>11.6</td>
<td>13.9</td>
<td>17.2</td>
<td>12.2</td>
</tr>
</tbody>
</table>

Dough preparing and baking procedure.

Natural rye flour leaven for 2014, which had been stored in a freezer at −18°C was used for baking. Before use, the leaven was melted at room temperature and refreshed by adding rye flour and water. The recipe for the rye bread: rye leaven 525 g, testing whole rye flour 600 g, wheat flour 350 g, salt 28 g, sugar 60 g, pressed yeast 10.5 g. Amount of the water added was calculated as follows: [content of dry matter of added components × 100 / (100 – moisture content of dough)] – total weight of added components. Moisture content of leaven was ~50%. Using wheat flour was necessary for several reasons (element for yeast, increasing volume of bread baked from whole rye flour). All compared bakings were done on the same day. The recipe was the same and the developed baking technology was followed exactly. The dough was mixed by hand in laboratory conditions. The quantity of leaven for the baking process was calculated so that 2/3 of leaven would be used for dough and 1/3 prepared as an ingredient for the next day’s baking. The components of dough were mixed in a bowl for about 4–6 minutes. The temperature of the water added was calculated on the premises that the dough temperature when placed in the oven should be 27–28°C. The mixing bowl was covered with moist linen cloth and left in a thermostat at 28°C for about 2 hours (depending on the acidity of the dough). The fermented dough portions intended for comparison were divided into three equal parts each and weighed. Loaves were put into oiled baking bowls and left in a thermostat at 38°C, the rising time was approximately 60 minutes. The baking regime: 10 min at 260°C and 35 min at 210°C. After baking, the bread loaves were covered with a towel and left to cool. After a few hours, each loaf was put into a plastic bag. Next morning, each loaf was weighed. Loaf volume was measured using the rapsedel displacement method according to AACC method 10-05-01 (http://methods.aaccnet.org/summaries/10-05-01.aspx). The volume of bread is presented as an average of three loaves (Table 3). Specific volume was calculated as follows: [content of dry matter of added components × 100 / (100 – moisture content of dough)] – total weight of added components.

600 g of the second phase leaven, mixture fermented for 4–4.5 hours until the final acidity of leaven is 12–13°, then stored in a freezer at −18°C.
of the viscosity of the sample continuously (viscogram). The analysis starts with the decomposition and expansion of starch. The process begins at 50–60°C. As the water penetrates the starch granules, the volume of the granules increases up to 10 times, indicating the viscosity of the starch. The viscosity peaks at 80–90°C. Statistical analysis. The annual results of the yield and quality parameters of rye grains were based on four replicates. The average data concerning the yield, quality parameters of grain, flour and breading during the experiment period (2008–2014) were based on seven replicates. The means for both organic and conventional treatments were compared using the least significant differences (LSD_{0.05} (P < 0.05).

**Table 2.** The yield and quality of winter rye grown in the organically and conventionally managed crop rotations during 2008–2014

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield t ha(^{-1})</td>
<td>ORG</td>
<td>3.01</td>
<td>3.22</td>
<td>3.10</td>
<td>1.66</td>
<td>1.76</td>
<td>1.94</td>
<td>3.94</td>
<td>2.66</td>
</tr>
<tr>
<td></td>
<td>CONV</td>
<td>4.52</td>
<td>5.14</td>
<td>3.98</td>
<td>3.56</td>
<td>2.96</td>
<td>4.67</td>
<td>4.09</td>
<td>4.13</td>
</tr>
<tr>
<td>Difference</td>
<td></td>
<td>1.57*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protein %</td>
<td>ORG</td>
<td>9.13</td>
<td>10.05</td>
<td>9.48</td>
<td>8.47</td>
<td>7.63</td>
<td>9.60</td>
<td>10.36</td>
<td>9.23</td>
</tr>
<tr>
<td></td>
<td>CONV</td>
<td>11.90</td>
<td>11.70</td>
<td>10.56</td>
<td>10.39</td>
<td>8.43</td>
<td>11.43</td>
<td>11.31</td>
<td>10.82</td>
</tr>
<tr>
<td>Difference</td>
<td></td>
<td>1.57*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000 kernel weight g</td>
<td>ORG</td>
<td>29.3</td>
<td>32.3</td>
<td>30.7</td>
<td>30.4</td>
<td>31.8</td>
<td>38.9</td>
<td>34.7</td>
<td>32.6</td>
</tr>
<tr>
<td></td>
<td>CONV</td>
<td>34.3</td>
<td>35.1</td>
<td>29.8</td>
<td>34.4</td>
<td>31.9</td>
<td>36.0</td>
<td>34.4</td>
<td>33.7</td>
</tr>
<tr>
<td>Difference</td>
<td></td>
<td>1.1 ns</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Results and discussion**

**Grain yield and quality.** Winter rye, in general, is not demanding concerning soil fertility, which is why it is an appropriate crop for cultivation in organically managed crop rotations. In a wide range of soil types, rye can thrive with a good yielding capacity. In soils of high natural fertility, rye can produce grain yields of moderate size for prolonged periods even without nutrient input. The previously mentioned properties were proven also in our experiment: in the sandy loam soil where no fertilizers had been applied since 2002, the grain yields in the organic treatment group reached up to 3–4 t ha\(^{-1}\) even after a number of years (Table 2). Such a yield level for the organic treatment could be retained due to a number of factors: the high natural fertility of the soil in the experimental area, the high-yielding clover ploughed into the soil before rye sowing, the straw and crop residues not removed from the crop rotation fields. The yields of rye varied highly depending on the year and treatment. For the seven-year experiment period, the average yields for the organic and conventional treatments were 2.66 and 4.13 t ha\(^{-1}\), respectively.

De Ponti et al. (2012), investigating the crop yield gaps between organic and conventional agriculture, have found that the yields of organically grown rye amounted to 76% (range 63–104%) of those obtained under conventional agriculture. As an average of our seven-year experiment, the rye yields of the organic treatment were 64% (range 42–96%) of those obtained for the conventional treatment. In 2011 and 2013, larger gaps in rye yields between the treatments were identified. This may be explained by the very harsh conditions in the winter rye cultivars of the Baltic States, the cultivar 'Elvi' is characterized by low to moderate TKW – 31.8 g. However, no significant (P < 0.05) differences in TKW between the treatments were found. The heaviest kernels (TKW 36–39 g) were produced in 2013 for both the treatments. This was the result of highly thinned vegetation caused by harsh winter and favourable weather conditions during rye growth and ripening. In addition, Tupits (2008) has demonstrated that rye plants on sparser plots are characterized by bigger kernels. According to Hansen et al. (2004), the kernel weight was negatively influenced by high temperature and drought during the ripening stage. In the summer months of 2010 and 2011, such weather conditions were prevalent, accounting for the lowest values of TKW during these harvest years.

The chemical analysis of mineral elements in rye grain showed that there were no significant differences in phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) contents between the organic and conventional treatments, or across experimental years. The dry matter (DM) of rye grains contained 0.37–0.43%, K 0.40–0.51%, Ca 0.07–0.11% and Mg 0.10–0.13%. The average content of nitrogen (N) in grains of the conventional treatment was significantly (P < 0.05) higher than that for the organic treatment, being 1.73% and 1.48% DM, respectively.

**Properties of rye flours.** The basic technological parameters of flour include the content and quality of proteins, content of ash, amylolytic activity, expressed as falling number, and moisture (Sujka et al., 2017). Rye flours, in general, are characterized by somewhat lower protein content than wheat flours. In rye baking, the amount and quality of protein is not as important as in wheat baking. Rye proteins do not form a gluten network but they seem to be important during the dough mixing step, since they have some aggregation abilities and are surface active (Banu et al., 2003; Dvořáková et al., 2012). Instead of gluten, the important quality factors for rye are the quality of starch and cell wall material, and the activities of endogenous enzymes modifying them (Dvořáková et al., 2011). It is well known in the milling and baking industry that the quality of rye flour can highly differ between years because the amylases activity is significantly affected by the temperature and amount of rain during the growing season (Hansen et al., 2004; Banu, 2006). Annually changing rye raw material requires a re-evaluation of baking process parameters and/or using of flour improvers to guarantee the stable quality of baked products (Mikola, Viskari, 2012). In our study, the analyses of rye whole grain flours used...
for the baking tests showed that the protein contents for the organic treatment varied somewhat more than these for the conventional treatment (Table 3). For the organic treatment, the average protein content was significantly \((P < 0.05)\) lower than that for the conventional treatment.

The ash content of cereal flours probably has no technological importance (Hansen et al., 2004; Suja et al., 2017); however, it is important as a source of minerals needed for healthy diet. Because the majority of minerals are located in the outer layer of the kernel, the ash content of flour indicates how much of the outer layers have been included in the flour. Traditional Nordic rye breads are made of whole organic rye flour (ash content about 2%) where all of the components of the kernel are present (Rye and health, 2002, http://rye.vtt.fi/rye&health.pdf). The ash content of rye flours derived from the grain yields during

\begin{table}[ht]
\centering
\caption{Properties of rye whole grain flours and breads depending on the cultivation methods}
\label{tab:table3}
\begin{tabular}{lcccccccc}
\hline
\hline
\multirow{9}{*}{Properties of rye flour} & Protein & ORG & 8.26 & 10.71 & 8.20 & 8.12 & 8.81 & 7.87 & 10.80 \\
& % & Difference & 1.65* \\
& Ash & ORG & 1.84 & 1.94 & 1.66 & 1.68 & 1.70 & 1.80 & 2.01 \\
& & CONV & 1.57 & 2.08 & 1.73 & 1.60 & 1.94 & 1.62 & 2.09 \\
& % DM & Difference & 19 ns \\
& Falling number, seconds & ORG & 110 & 175 & 267 & 234 & 78 & 124 & 403 \\
& & CONV & 120 & 175 & 268 & 172 & 62 & 72 & 289 \\
& Difference & 19 ns \\
& Starch & ORG & 62.9 & 62.5 & 66.8 & 66.5 & 63.2 & 64.1 & 65.2 \\
& & CONV & 61.4 & 61.1 & 64.0 & 62.9 & 62.1 & 61.9 & 64.5 \\
& % DM & Difference & 1.9% \\
& Properties of bread & Loaf volume cm³ & ORG & 1464 & 1582 & 1459 & 1356 & 1393 & 1226 & 1345 \\
& & CONV & 1499 & 1552 & 1470 & 1410 & 1356 & 1099 & 1489 \\
& Specific volume cm³ g⁻¹ & ORG & 2.10 & 2.25 & 2.14 & 2.06 & 2.00 & 1.80 & 1.96 \\
& & CONV & 2.10 & 2.16 & 2.16 & 2.10 & 1.99 & 1.96 & 2.11 \\
& Specific volume:protein & ORG & 0.24 & 0.29 & 0.26 & 0.25 & 0.22 & 0.23 & 0.18 \\
& & CONV & 0.24 & 0.20 & 0.21 & 0.20 & 0.21 & 0.14 & 0.19 \\
& Moisture % & ORG & 47.8 & 49.8 & 48.1 & 47.9 & 47.5 & 50.0 & 49.0 \\
& & CONV & 48.6 & 48.6 & 47.6 & 48.3 & 48.0 & 47.8 & 49.0 \\
& Acidity º & ORG & 6.0 & 6.1 & 6.5 & 6.6 & 6.5 & 6.0 & 6.5 \\
& & CONV & 6.0 & 6.6 & 6.4 & 6.3 & 6.5 & 6.2 & 6.4 \\
& Porosity % & ORG & 55 & 57 & 60 & 53 & 45 & 49 & 49 \\
& & CONV & 58 & 57 & 53 & 54 & 50 & 50 & 52 \\
\hline
\end{tabular}
\end{table}

DM – dry matter; ORG – organic without fertilizers, CONV – conventional with fertilizers and herbicides; * – difference is significant by LSD test at \(P < 0.05\), ns – not significant

our experiments in 2008–2014 was in the range of 1.6–2.1% DM and there were no significant differences between cultivation methods. It could be mentioned that the higher ash contents (1.9–2.1%) were registered for rye yielded in 2009 and 2014. This was probably caused by the fact that in these years, rye was grown in the crop rotation field No. 1 that adjoins a gravel road and the gravel dust might, to a certain extent, have polluted the developing grains.

The falling number offers useful information about the starch gelatinization phenomenon and the extent to which it is influenced by the amylolytic enzymes (Banu, 2006). Falling number determines the ability of dough to start and maintain fermentation process (Suja et al., 2017). The amylases activity is easily measured by Hagberg falling number and it is known that decreasing falling number values of rye flour for the conventional treatment showed much lower values than for the organic treatment in some years (2011 and 2013), the difference was not significant \((P < 0.05)\) for the entire 7-year experimental period. However, Basinskieni et al. (2011), comparing enzymatic activity of cereals in different farming conditions, have found that the average α-amylase activity in organically grown rye was by 23% lower than that measured in conventionally grown rye samples, while the opposite trend was found for endoαxylanase activity.

Starch is the major contributor to rye bread (Banu et al., 2011). Rye starches exhibit greater values of solubility in cold water compared to wheat starches (Anderson et al., 2011). Rye starch is amylolytic enzymes in rye flour increases, which results in deteriorated rheological properties of dough and unsatisfying quality of baked product (Dojczew et al., 2004). Low falling number (under 100 sec) of flour made from sprouted grains is caused by the increased content of α-amylase. To decrease its amylolytic activity, the acidity of the dough needs to increase as well. This means that the dough will be prepared with leaven, which brings on the fast inactivation of α-amylase in the baking process (Auermāns, 2003; Nowotna et al., 2006).

In our experiment, the falling number values of rye flour were distributed across a wide scale depending on the harvest years – varying by up to four times. The lowest falling number values (about 70 sec) of flours were recorded in 2012. This can most probably be explained by unfavourable growing conditions of the year: cool, cloudy and rainy periods lasted too long, delaying rye growth, as well as complicating the harvest. Although the falling number of rye flour for the conventional treatment showed much lower values than for the organic treatment in some years (2011 and 2013), the difference was not significant \((P < 0.05)\) for the entire 7-year experimental period.
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β-amylase loses its activity at a much lower temperature compared to α-amylase (Banu et al., 2011). Different enzymes are characterized by different temperature dependencies. For instance, the activity of α-amylase on the degradation of starch molecule (Hoog, 1969; Mühlenchemie Glossary, www.muehlenchemie.de/english/know-how/glossary.html). β-amylase splits maltose off the ends of the chains of the starch molecules. In dough, the sugar formed by β-amylase can be used by the yeast for fermentation and contributes to the softening of the baked goods.

Viscographic tests of flours and properties of breads. Bread-making technology is based on the activity of various enzymes, which in turn are influenced by environmental conditions. The grain of the conventional treatment was more susceptible to Fusarium spp. lodging and might have been contaminated with soil. The grain of the conventional treatment in 2012 had a lower falling number (72 sec) than the organically grown rye grain (65 sec). In this year, rye flour was less productive for dough development, and the maximum viscosity was lower for the conventional treatment (Table 3). The starch content for organically grown rye flour was significantly (P < 0.05) higher for conventionally grown rye, as the average for the experiment period.

Water binding capacity of flour is one of the most important characteristics for the bread baking process. As is generally known, rye doughs often require a higher proportion of water than doughs in which wheat protein can be expected to provide the higher content of rye flours, especially when milled from rye whole grain. The high water binding capacity of rye flour can also be explained by the higher content of water-soluble pentosans, especially when milled from rye whole grain meal. The high water binding capacity of rye flour remains quite stable (147–152 ml per 100 g flour) and did not depend on the treatments or years. According to Hansen et al. (2004), the water absorption capacity of rye whole grain meal is mostly influenced by genotype effects and less by harvest years.

In our experiment, the content of starch in whole grain flour for the conventional treatment varied from 62.5% to 66.8% DM and that for the conventional treatment from 61.1% to 64.5% DM. The starch content for organically grown rye flour was significantly higher than for conventionally grown rye, as the average for the experiment period.

If we compare the impacts of the organic and conventional treatments, we find the inverse correlation (r = –0.596) between starch and protein content also for the rye flours. The viscographic analyses of the rye flours derived from the grain yields of years 2012, 2013 and 2014 were carried out by using Brabender Viscograph. As the content and activity of amylase enzymes was not investigated for the present research, we will interpret the viscograph readings only briefly, relying on the practical and literary knowledge. We will compare the viscosograms of 2012 and 2014. In these years, the starch content of flours differed by about 2% (Table 3).

The starch gelatinization began at the same temperature (55°C) but the time to maximum viscosity was different (Table 4). In 2012, the maximum viscosity was reached after 27 min, whereas for the conventional treatment, the maximum viscosity was more than 5-fold for the 2012 flours, but only 2-fold for 2014. This might be due to different activity of α-amylases because the falling numbers of flours were drastically different (about 70 sec in 2012 and 300 sec in 2014 (Table 3). There were no significant differences in the loaf volumes. However, the higher activity of α-amylase (2012) was measurable in the bread porosity: the denser the bread crumb (the pores are compact), the lower porosity.

In 2013, extraordinarily weak viscographic results and low falling number (72 sec) of flour were proven for the conventional treatment. In this year, rye harvesting was delayed due to unfavourable harvest conditions. The grain of the conventional treatment lodged and might have been contaminated with soil and pathogenic fungi. As the pathogen Fusarium spp. destroys starch granules, storage proteins and cell walls, this subsequently affects the quality of dough properties (Papouskova et al., 2015). In 2013, for the conventional treatment, the bread volume was by far the smallest (only 1099 cm³) among all the samples of the experimental period. Rye flour of such low quality seems to be unsuitable for bread-making only if mixed with wheat flour in accordance with the relevant dough recipe.

The viscosograms of rye flours varied widely between the years and treatments. This is understandable because the flours and doughs are a living environment, containing various enzymes, yeasts, lactic acid bacteria, which work simultaneously and have very different mutual impacts and relationships.

If we consider the impacts of the organic and conventional treatments, then in spite of several fluctuations in the flour properties and viscosograms, there were no significant differences in the properties of the end product as described in the average results for the seven-year experimental period. So, it might be concluded that by using the flours of organically grown rye and...
conventionally (with the moderate input of synthetic fertilizers and herbicides) grown rye, we can produce the breads of the same quality.

**Conclusions**

1. The seven-year experiment on a sandy loam *Alliic Stagnic Luvisol* showed that the yields of organically grown winter rye varied significantly (1.7–3.9 t ha⁻¹) across years, and remained, on the average, at 64% of those obtained under conventional (CONV) treatment.

2. The protein content in rye grains depended on the year and treatment, being significantly (*P* < 0.05) lower for the organic (ORG) treatment. No significant differences in the 1000 kernel weight and kernel chemical composition (P, K, Ca and Mg content) were established between the treatments.

3. The analyses of rye whole grain flour showed that the falling number and the ash content were not affected by cultivation methods; however, falling number varied significantly during the experimental years. The flour derived from organically cultivated rye was characterized by significantly (*P* < 0.05) higher starch content than the conventional flour. An inverse correlation (*r = −0.596*) was established between starch and protein contents in rye whole grain flour. The water binding capacity of flours was quite stable (147–152 ml per 100 g flour) for the all cases in our investigation.

4. The pasting behaviour of rye whole grain flour was characterized by significantly (*P* < 0.05) lower starch and protein content in rye whole grain flour. The water binding capacity of flours was quite stable (147–152 ml per 100 g flour) for the all cases in our investigation.

5. The results of baking tests demonstrated that the bread volume and quality properties of baked breads do not depend on the cultivation method of winter rye. It may therefore be concluded that breads produced from rye grown under organic farming and/or properly managed conventional farming by the means of sourdough fermentation are practically of the same quality.

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Ekologiskai ir tradiciškai augintų žieminų rugių produktyvumas, kokybė ir duonos kepamosios savybės

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