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Winter rye grain quality of hybrid and population cultivars

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Abstract. Rye (*Secale cereale* L.) is an important European crop used for food that is grown primarily in Eastern, Central and Northern Europe. Consuming rye grain products provides a rich source of dietary fibre as well as several bioactive compounds with potentially positive health implications. The goal of the research was to compare the rye grain quality of hybrid and population cultivars. A field trial was carried out in Priekuli Research Centre, Institute of Agricultural Resourses and Economic (in Latvia) during a three-year period: 2014/2015, 2015/2016, and 2016/2017. The trial included population winter rye cultivars 'Kaupo', 'Amilo', 'Dankowskie Amber' and hybrid rye cultivars 'Brasetto', 'Su Drive', 'Su Mephisto'. Rye grain quality indices were analysed at Latvia University of Life Sciences and Technologies, in Grain and Seed Research laboratory. Average data in our investigation (three years) show that cultivar, crop-year (weather conditions) and cultivar×crop-year interaction significantly ($P < 0.05$) affected rye grain protein content, starch content and Hagberg falling number. A significant negative correlation was found between protein content and starch content $r = -0.937$ (population cultivars grain), $r = -0.944$ (hybrid cultivars grain), medium strong negative correlation was found between protein content and falling number, respective $r = -0.549$ and $r = -0.573$. Differences between hybrid cultivar grain protein content, falling number and starch content comparing with population cultivar grains were not observed. The results of the current research show that the quality of all the studied cultivars meets the requirements for high-grade rye grains for food consumption.

Key words: winter rye, protein content, starch content, Hagberg falling number.

INTRODUCTION

Winter rye (*Secale cereale* L.) is an important grain crop in Latvia, where it is mainly used for baking rye bread, which is a popular staple. The chemical composition of rye grain promises health benefits and it contributes to higher intake of dietary fibre. The chemical composition of rye grain differs from wheat, rye contains less starch and protein but more dietary fibre than wheat (Linina & Ruza, 2012; Alijošius et al., 2016). In rye flours 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., 2006). Protein composition and contents play a critical role in bread quality and are governed by a combination of genetic and environmental factors (Hansen et al., 2004). Rola et al. (2008) stated that protein content among the different population cultivars of rye ranged between 9.4% ('Palazzo') and 11.3% ('Virgiai'), while Vidmantiene & Juodeikiene (2010) reported that protein content was from 7.5% to 11.2%, similarly also Stępniewska et al. (2018): 8.0–11.1%.

Starch is an important ingredient of rye flour. Its properties and quality determine the usefulness of flour for bread baking (Laiding et al., 2017).

Rye quality depends on weather conditions in the growing years (Chmielewski & Kohn, 2000; Nowotna et al., 2006; Kučerová, 2009; Blecharczyk et al., 2016; Kottman et al., 2016). Rye is sensitive to the prevailing weather conditions, such as precipitation. Rainy periods in the ripening stage sometimes cause the pre-harvest sprouting of rye grains. Low falling number (under 100 s) of flour made from sprouted grains is caused by the increased content of α-amylase (Dvorakova et al., 2012). The falling number is of significant meaning as it describes the α-amylase activity in flour. Excessive α-amylase activity has an adverse effect on the quality of baked products. Falling number depend on agrotechnical and weather conditions as well as on genetically determined plant properties (Dubis et al., 2008, Linina & Ruza, 2015).

Hybrid rye breeding started in 1970 at the University of Hohenheim in Germany and the first hybrid cultivars were reased in Germany at 1984 (Wang et al., 2014). Economically important traits in hybrid rye are grain yield and plant height in context of productivity as well as starch content and total pentosan content with regard to end user quality. Hybrids are grown on about 60–70% of the total rye acreage owing to their yield superiority and better uniformity as compared to population cultivars. German commercial hybrid cultivars are also realised and grown in Denmark, Austria, Poland (Miedaner & Hübner, 2011) and Latvia.

Grain yield and quality significantly varied depending on the cultivars as previously observed (Peltonen-Sainio et al., 2007; Wang et al., 2014; Alijošius et al., 2016; Linina & Ruza, 2018). Rola et al. (2009) reported that falling number was from 160 to 325 s in population rye cultivar 'Fernando' and from 113 s to 297 s in hybrid cultivars 'Stach' grown in Poland, while protein content, respectively: from 7.9% to 12%, and from 8.4% to 11.6%.

Quality indices of winter rye are not stable between production years because of the inconsistency of the variables, such as initiation of the growing season, distribution of rainfall and heat units available for crop growth during corresponding phases of plant growth and development (Hansen et al., 2004).

The goal of the research was to compare the rye grain quality of hybrid and population cultivars.

MATERIALS AND METHODS

Field experiments. A field trial was carried out in Priekuli Research Centre, Institute of Agricultural Resources and Economics in 2014/2015, 2015/2016 and 2016/2017. The soil type was sod-podzoloic loam, with close to neutral acidity (pH_{KCl} 5.6–6.0), medium high phosphorus and potassium, organic mater 1.7–2.5 g kg^{-1}. In trial traditional soil treatment was used, which involves soil ploughing. Winter rye population cultivars (POP) 'Kaupo' (Latvia), 'Amilo', 'Dankowskie Amber' (both Poland) and hybrid cultivars (HYB) 'Brasetto', 'Su Drive', 'Su Mephisto' (all Germany) was sown (17 September in 2014, 24 September in 2015 and 19 September in 2016) after spring barley. Seeding rate was 500 seeds per 1 m^2. Trials were arranged using split plot design in four replications. Before sowing in autumn complex mineral fertilizers ensuring following amounts of pure elements were applied: N12, P_2O_5 52, K_2O 60 kg ha^{-1}. Nitrogen (N) was applied N68 kg ha^{-1} in spring after resumption of vegetative growth and N31 kg ha^{-1} at the shooting stage (BBCH-scale). All the necessary plant protection measures (herbicides, plant growth regulators and fungicides) were performed. Rye grain was harvested at full ripening (BBCH-scale: 90–92) on 4 August in 2015, on 5 August in 2016 and on 3 August in 2017. Harvested grain of each cultivar and replication was put into separate bags. The grain with a moisture content exceeding 14% was dried.

Weather conditions. During three investigation years weather conditions were different. Winter rye sown in 2014, 2015 and 2016 overwintered successfully. The winter of 2014/2015, 2015/2016, 2016/2017 were generally favourable for rye wintering. The air temperature in investigation years (Fig. 1) in April was close to long-term mean (LTM) observations. May in 2015 and 2017 was colder, while in 2016 it was 2.7 °C warmer, which promoted plant growth and development. Average daily temperature in June 2015 and 2017 was lower compared to long-term average data, in 2016 air temperature was warmer by 1.5 °C which contributed to the accumulation of protein. Temperature in the grain filling period (July), which is the most decisive for grain quality formation, was colder in 2015 and 2017, while in 2016 it was by 1 °C higher than the long-term average mean data.

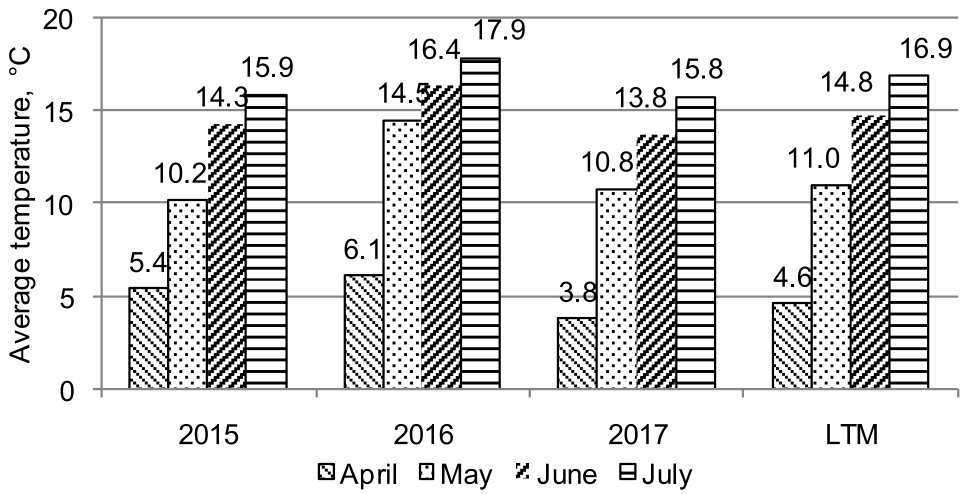

Figure 1. Average air temperature in vegetation period, and long-term mean (LTM) °C.

Water availability has effect on rye grain quality. Precipitation in April 2015, 2016 and 2017 was more than long-term means data. May in 2016 was dry. Precipitation in June 2015 was less than to long-term mean, while in 2016 and 2017 was more than long-term means data. Precipitation in all investigation years was close to long-term average observations (Fig. 2).

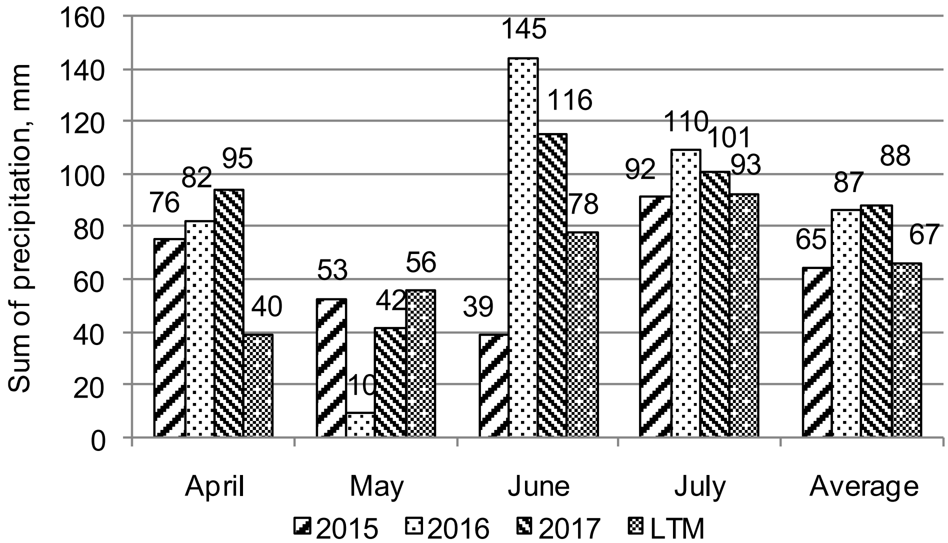

Figure 2. Average sum of precipitation, and long-term mean, mm.

Sample analysis. The rye grains were analysed at Latvia University of Life Sciences and Technologies in Grain and Seed Research laboratory. Quality indices: protein content (%) and starch content (%) were analysed by grain analyser Infratec 1241 (FOSS, Denmark), which employs the near-infrared analysis within the wavelength range 570–1,110 nm. The Hagberg falling number – α-amylase activity – was measured by the Hagberg-Perten method using a Perten Instruments (Sweden) Falling number 1500 assessed to LVS EN ISO 3093 using 7 g of flour adjusted for moisture content to 15%.

Statistical analysis. Experimental data evaluation was done using two factor analysis of variance by Fisher's criteria, which were applied to estimate the effects of year (meteorological conditions) and cultivars. Component of variance ANOVA for each quality characteristic was expressed as percentage to illustrate the relative impact of each source to the total variance. Differences of the grain quality indices between population and hybrid rye cultivars were determined by t-test: Two Sample Assuming Unequal variance. Correlation analysis between protein content and other grain quality indices was carried out.

RESULTS AND DISCUSSION

The content of protein, starch and falling number are two important criteria for the quality of cereals (Miedaner et al., 2012; Stępień et al., 2016). Rye quality is subject to large year-to-year fluctuation (Laiding et al., 2017). In our investigation grain protein content, starch content and falling number significantly ($P > 0.05$) varied depending on the cultivars and meteorological conditions. The least variation of the grain starch content (average 61.4%) was noticed in the hybrid cultivars, with coefficient of variation of 3.1%. The greatest variations of the falling number (average 230%) were observed in population cultivars: V = 21.4% (Table 1).

Table 1. Winter rye quality indices

Indicators	Population cultivars (POP)			Hybrid cultivars (HYB)		
	PC, %	SC, %	FN, s	PC, %	SC, %	FN, s
Mean ± standard error	10.3 ± 0.7	61.4 ± 0.8	230 ± 16.4	9.8 ± 0.6	61.4 ± 0.6	230 ± 13.0
min	7.7	58.8	130	7.7	58.8	158
max	13.1	64.8	305	12.2	64.1	275
V %	19.4	3.9	21.4	18.4	3.1	18.5

PC – protein content; SC – starch content; FN – falling number.

The **protein content (PC)** in population cultivars ranged from 7.7% (‘Kaupo’) to 13.1% (‘Amilo’), similarly, it was also for hybrid cultivars: from 7.7% (‘Su Drive’) to 12.2% (‘Brasetto’) (Fig. 3). The investigation with winter rye in the western region of Lithuania indicates small changes of protein content 7 to 8% (Skuodienė & Nekrošienė, 2009), while in Estonia (seven years study of winter rye cultivar ‘Elvi’) it was 8.4 to 11.9% (Järvan et al., 2018) and 9 to 13% in Serbia (Žilic et al., 2011). The content of protein rye grain was differentiated by weather conditions in the years. In harvest year 2016 the content of protein in rye grains was higher as compared with other years. In 2016 a higher mean air temperature in summer favoured a greater concentration of protein. Similar dependences of protein accumulation on weather conditions were confirmed by the study of Stępień et al. (2016). In rye baking the amount and quality of protein are not as important as in wheat baking (Salmenkallio-Marttila & Hovinen 2005); also grain processing companies in Latvia do not take this into account.

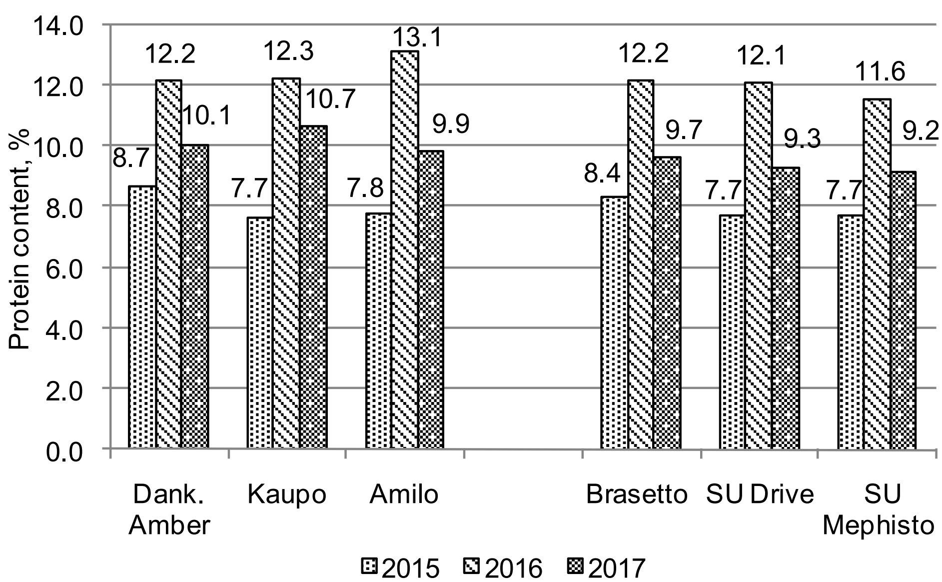

Figure 3. Winter rye grain protein content, %.

Influence of each factor (crop-year, cultivar and crop-year×cultivar interaction of them) was calculated of two-factor analysis of variance for winter rye protein, starch content and falling number. It was expressed as percentage to the total variance. Data in our experiment (3 years) suggest that protein content was significantly ($P < 0.05$) influenced by harvest year (POP 95.0%, HYB 97.2%), while cultivars (POP 0.1%, HYB 2.0%) and cultivar×crop-year influence were small (POP 4.8%, HYB 0.4%) (Table 2). However, in experiments performed in Denmark (Hansen et al., 2004) protein content in rye grain dependency on cultivar complete to 67%, the influence of year – 17%, but cultivar×crop-year influence was small – 4%.

Table 2. Impact factors of rye grain quality indices, %

Source of variation	Population cultivars (POP)			Hybrid cultivars (HYB)		
	PC, %	SC, %	FN, s	PC, %	SC, %	FN, s
Year (Y)	95.0	96.6	46.5	97.2	92.8	80.5
Cultivar (C)	0.1	0.9	29.5	2.0	4.9	11.2
Y × C interraction	4.8	1.6	22.0	0.4	1.3	7.4

PC – protein content, SC – starch content, FN – falling number.

Starch is an important ingredient of rye flour. Its properties and quality determine the usefulness of flour for bread baking. Rye starches exhibit greater values of solubility in comparison to wheat (Banu et al., 2006).

The average winter rye **starch content (SC)** (Fig. 4) in three investigation years was from 58.8% to 64.8% (POP), which was very similar to the HYB: 58.8 to 64.1%. The content of starch measured in this study is in accordance with the findings by other authors (Marczewski et al., 2012; Miedaner et al., 2012; Wang et al., 2014; Järvan et al., 2018). The starch content was significantly ($P < 0.05$) influenced by year (POP 96.6%, HYB 92.8), while cultivar influence (POP 0.9%, HYB 4.9%) and cultivar×crop-year influence (POP 1.6%, HYB 1.3%) were small (Table 2).

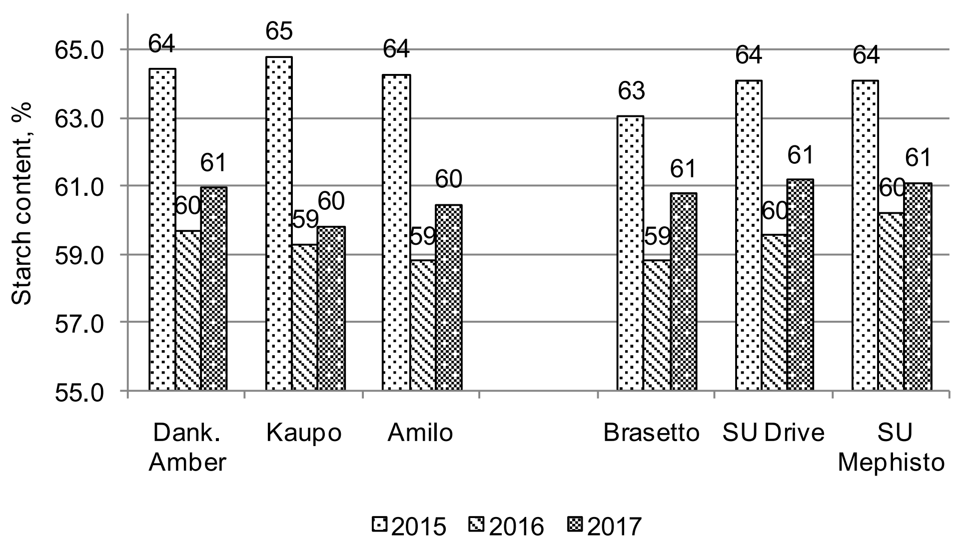

Figure 4. Winter rye grain starch content, %.

Falling number (FN) is the most commonly used method for rye quality control. Falling number is an indication of degree of soundness of rye in terms of freedom from sprouting which causes the production and activation of α-amylase inside the rye kernel which, in turn, has a very drastic effect on the dough and bread making process. To obtain rye flour with the falling number level appropriate for the baking process one should use grain with the falling number within the interval 110–190 s (Salmenkallio-Marttila & Hovinen, 2005). In Latvia the falling number of rye flour used from bread baking is 120 s.

In our investigation the falling number of grain was significantly ($P < 0.05$) different for cultivars. Falling number in population cultivars ranged from 130 s ('Kaupo') to 305 s ('Amilo'), for hybrid cultivars: from 158 s ('Su Drive') to 275 s ('Brasetto') (Fig. 5).

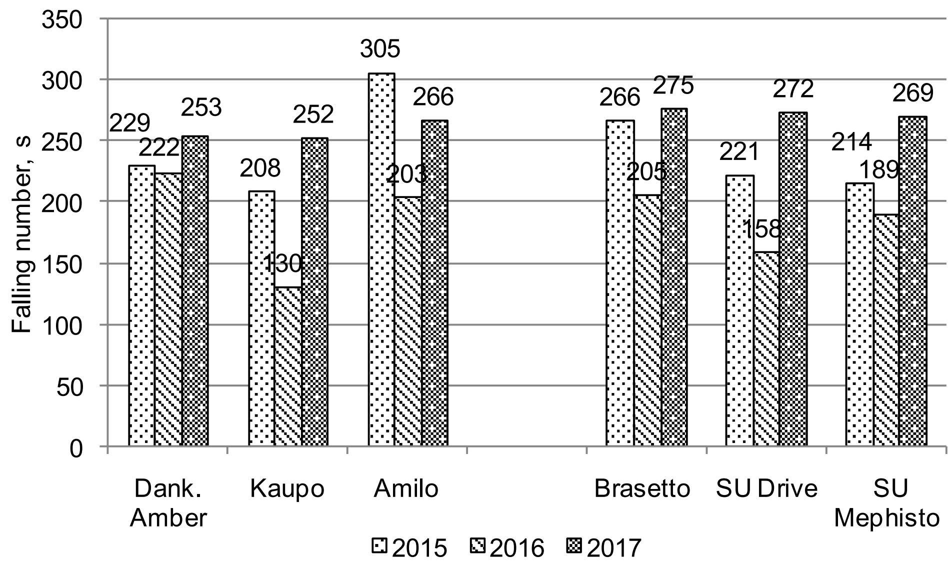

Figure 5. Winter rye grain falling number, s.

Salmenkallio-Marttila & Hovinen (2005) in Finland determined that the falling number from rye population cultivars was lower (111–204 s), compared to hybrid cultivars (256–261 s). Zdubel et al. (2009), Vidmantiene & Joudeikiene, (2010), Marczewski et al. (2012) and Ismagilov et al. (2018) also confirmed that the falling number of different cultivars may vary in the same growing conditions. In the present trial, differences between hybrid cultivar grain protein, starch content and falling number in comparison with the population of cultivar grains were not observed (*t-test,* $P < 0.05$). All properties of winter rye demonstrate that the quality of the studied cultivars corresponds to the requirements for high-grade rye for food consumption.

Weather conditions in investigation years influenced grain α–amylase activity. The falling number is affected by precipitation during grain maturation. High rainfall in grain maturation period results in higher α-amylase activity and lower falling number (Salmenkallio-Marttila & Hovinen, 2005). In Järvan et al. (2018) trial, the falling number for rye grain (seven crop-years) was from 62 to 289 s. In our investigation rainfall in 2016 during rye grain maturation was exceeded the long-term mean data, therefore falling number for rye grain was lower.

The falling number was influenced by crop-year (POP 46.5%, HYB 80.5%) and cultivar (POP 29.5%, HYB 11.2%) whereas the effect of cultivar×crop-year accounted: POP 22.0% and HYB 7.4%) (Table 2), similar results have also been demonstrated by Hansen et al. (2004).

A significant negative correlation was found between rye grain protein content and starch content $r = -0.937$, $R^2 = 0.878$ (POP), $r = –0.944$ (HYB) $R^2 = 0.891$ (n = 12, $\alpha_{001} = 0.708$, $\alpha_{005} = 0.576$) (Fig. 6). Similar results were obtained in previous research in Germany (Miedaner & Hübner, 2011; Miedaner et al., 2012) and also in Estonia (Järvan et al., 2018).

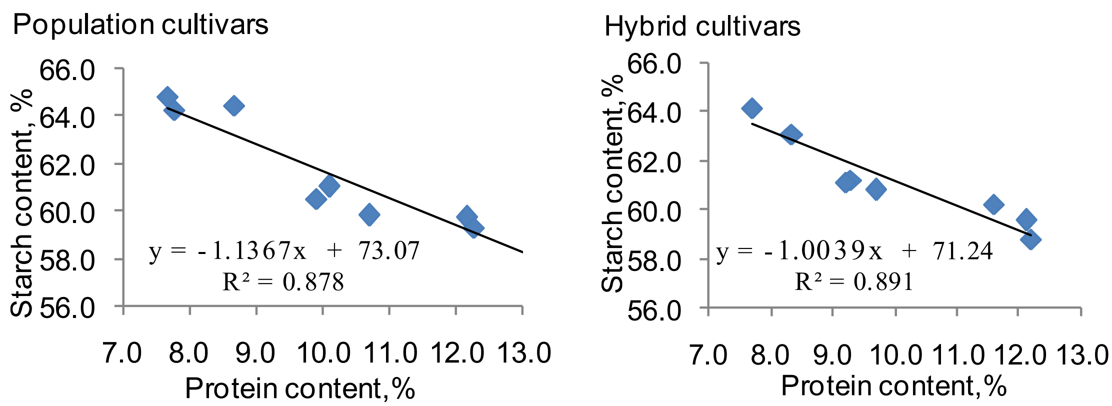

Figure 6. Winter rye grain starch and protein content relationships.

Medium negative correlation was found between protein content and falling number, respective $r = -0.549$ (POP) and $r = -0.573$ (HYB).

CONCLUSIONS

In the present research it was found, that rye cultivar, differences in their genetic as well as weather conditions significantly influenced protein formation in grains. Higher protein content was found in the analysed rye samples in the period when the growing conditions were warmer (2016). Lower falling number was obtained in winter rye grain, in 2016 because there was more precipitation in June and July. Differences between hybrid cultivar grain protein and starch content, falling number in comparison with population cultivar grains were not observed. Winter rye properties demonstrate that the quality of the studied cultivars correspond to the requirements for high-grade rye for food consumption. The strong negative correlation was found between protein content and starch content.

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