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# Genetic material of tall-growing winter rye for varietal improvement

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The main tasks of the present study were to identify the properties specific to tall- and short-growing rye varieties developed up to now or in the recent past and the tall-growing varieties that could be included in the rye breeding programmes as a genetic source for variety improvement, as well as the influence of plant height on the other characteristics. Field experiments were conducted at the Lithuanian Institute of Agriculture in 2002–2004. The experimental material included 21 varieties and 19 advanced breeding lines developed at the Plant Breeding Centre over the recent years. Our experimental evidence suggests that tall-growing winter rye is a valuable genetic resource for winter rye varietal improvement. Paired regressions revealed the highest positive correlation between plant height and grain yield. The number of spikelets per spike, grain number per spike, grain weight per spike, 1000 grain weight, grain weight per plant positively correlated with plant height too. Taller plans have longer spikes, however, longer spikes tend to develop a higher number of empty spikelets. A high negative correlation between stem height and Falling Number index was identified. Varieties with taller stems were less susceptible to brown rust, but the correlation was not significant both for brown rust and powdery mildew. Plant height negatively correlated with plant lodging. Grain yield tended to negatively correlate with lodging, but the correlation was not significant. This suggests that-among tall growing accessions it is possible to select a valuable genetic material for varietal improvement.

The analysis of the investigated accessions showed that among the tallest varieties (>130 cm) only three varieties were susceptible to plant lodging The lodging resistance of the variety 'Tulvi' and lines LIA 512, LIA 490, LIA 521, LIA 458, LIA 395 was estimated as good or acceptable. The grain yield of these accessions was 5.20, 7.55, 5.60, 6.86, 7.05, 6.10 t/ha respectively. The Falling Number index, indicating grain quality, was more than 200 s. The most valuable genetic source for further breeding programmes was found to be lines LIA 512, LIA 521 and LIA 458, which were the highest yielding and characterised by a high grain quality and tolerance of plant diseases.

**Key words**: winter rye, varieties, plant height, grain yield, spike characteristics

## INTRODUCTION

Tall-growing rye varieties, well adapted to the local conditions, have been traditionally planted in Lithuania [1]. Nevertheless, these varieties have some disadvantages such as susceptibility to lodging and high energy consumption at harvesting due to a high straw biomass. Short stem varieties, which had been introduced over the last decades, did not solve all the problems. They were more susceptible to plant diseases and showed a lower winter hardiness.

In accordance with the Lithuanian Institute of Agriculture's Plant Genetic Resource Programme, the rye genetic collection includes varieties with a diverse stem height. The main tasks of the present study were to identify which properties are specific to tall- and short-growing rye varieties and lines developed up to now or in the recent past, how tall-growing varieties can be included in the rye breeding programmes as a genetic resource for variety improvement, and the effect plant height exerts on the other characteristics.

Coming back to tall-growing rye varieties as a genetic resource for the further breeding of rye is important due to the new approach to crop management. Adequate genotypes require sustainable and organic farming.

Rye breeders put a lot of attempts to developing short-stem varieties, so that plants could be able to effectively uptake the increasing nitrogen rates. Commercial striving of seed companies to secure "biological variety protection" stimulates development of hybrid rye varieties. Organic plant breeding prohibits application of some cytoplasmic male sterility techniques in plant breeding [2, 3]. This means that the use of hybrid rye varieties might be restricted for organic farming systems. The application of fertilizers and pesticides should be decreased in general, and on organic farms it should not be used at all. Therefore the plant breeding programmes should be aimed to developed varieties, satisfactorily performing at modest nutrition levels and without chemical protection agents. The fact of genetic erosion is important for rye varieties, because the breeders often use the most intensive varieties for the development of new cultivars, which have a relatively narrow genetic basis [4]. Inclusion of tall-growing rye in the crossing programmes is important for germplasm enrichment of the varieties which will be grown in the future and for developing cultivars suitable for sustainable and organic growing conditions.

## MATERIALS AND METHODS

The field experiments were conducted at the Lithuanian Institute of Agriculture during 2002–2004. The experimental material included 21 varieties and 19 advanced breeding lines developed at the Cereals Breeding Department over the recent years.

Grain yield (t $ha^{-1}$), 1000 grain weight (g), plant height (cm), plant lodging (score 1= full lodging, 9 = no lodging), Falling Number index, protein content, starch content, test weight, spike length, number of spikelets per spike, grain number per spike, grain weight per spike, percentage of empty spikelets were recorded and analyzed in the experiment. The incidence of the following plant diseases was assessed: leaf rust (*Puccinia recondita* Rob. ex Desm.), stem rust (*Puccinia graminis* Pers. *f.* sp. *secalis* Erikss. & Hen.) and powdery mildew (caused by *Blumeria graminis* DC. f. Speer). Assessments of powdery mildew in rye were done at heading stage (DC 51-59), brown rust at milky stage (DC 71-75), and stem rust before harvesting (DC 87-89) [5].

The test plots were 2 $m^2$. Nitrogenous, phosphorous and potassic fertilizers ($N_{90}$ $P_{24}$ $K_{43}$) were applied annually. The growing and harvesting conditions in 2002–2003 were favourable. During the experimental period the air temperature was higher than the long term mean covering the 1924–2003 period. The precipitation level ranged from normal to low.

Analyses of grain quality were done at the Analytical Laboratory of LIA using conventional methods and facilities. The protein content was measured by the Kjeldhal method, starch content by GOST 10845, amylases activity by Perten's Falling Number 1800 (standard ICC No. 107). Statistical data processing was performed with the ANOVA and STATENG software using the programme "Selekcija" [6].

## RESULTS AND DISCUSSION

The study involved winter rye varieties and lines differing in plant height (Table 1). The average stem height of the shortest variety recorded in 2002–2004 was 83.9 cm ('Piccaso'), and of the tallest line 138 cm (LIA 413) . The tallest varieties and lines were mostly of Lithuanian and Estonian origin. This type of cultivars possesses a higher cold tolerance, which is relevant in Nordic countries. Winter resistance of the varieties was not included in the analysis, because the winter conditions during the experimental period were mild and none of the varieties were damaged. In earlier observations we noted that short-stem varieties were less resistant to severe winter conditions. Other authors have reported similar findings [7].

Grain yield among the varieties and lines fluctuated from 3.10 to 7.55 t $ha^{-1}$. The grain yield of the cultivars with a stem height from 120 to 138 cm varied from 5.20 to 7.55 (average yield 6.37 t $ha^{-1}$), while the yield of the cultivars with a stem height from 83.9 to 116.8 cm varied from 3.10 to 6.10 (average yield 4.85) t $ha^{-1}$. The local varieties and lines were characterized by the highest grain yield. The paired regression analysis suggested that plant height positively correlated with grain yield. The coefficient of correlation was 0.829, $R^2$ = 0.687, Ft = 83.38 P, equation of regression was $y = -0.33 + 0.052\ x$ (Table 2). In our experiment, plant height negatively correlated with plant lodging, the coefficient of correlation being 0.436, $R^{2-}$= 0.19; Ft = 8.9 ($P < 0.01$).

Grain yield depends on many traits: number of spikelets per spike, grain number per spike, grain weight per spike, 1000 grain weight, and grain weight per plant. These traits positively correlated with plant height, ($R^2$) = 0.307; 0.224; 0.309; 0.129; 0.188, (Ft) = 16.87 ($P < 0.01$); 10.98 ($P < 0.01$); 17 ($P < 0.01$); 5.61 ($P < 0.05$); 8.78 ($P < 0.01$), respectively. Taller plans generally have longer spikes, the correlation coefficient XY = 0.475, $R^2$ = 0.307, Ft = 16.87 ($P < 0.01$), but longer spikes have some disadvantages as they tend to develop more of empty spikelets (XY = 0.316, Ft = 4.51 ($P < 0.05$), $R^2$ 0.1).

Another disadvantage of tall-growing rye is a higher activity of amylases, which makes its grain qua-

Table 1. **Mean values of plant height, yield, 1000 grain weight, Falling Number, lodging, spike characteristics, and disease incidence in winter rye varieties and lines**

| Varieties and lines | Plant height, cm | Grain yield, t $ha^{-1}$ | 1000 grain weight, g | Falling number index | Lodging, score 1–9 | Length of spike, cm | Grain number per spike | Grain weight per spike | Empty spike lets, % | Incidence of brown rust, % | Stem rust, % | Powdery mildew, % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LIA 413 | 138.0 | 6.60 | 35.8 | 179 | 6.9 | 11.5 | 62.4 | 2.3 | 20.3 | 26.6 | 10.6 | 14.4 |
| LIA 423 | 137.0 | 6.38 | 37.3 | 214 | 5.6 | 9.9 | 56.7 | 2.2 | 18.6 | 18.0 | 4.0 | 8.5 |
| Elvi | 134.1 | 6.80 | 38.6 | 170 | 6.5 | 9.9 | 62.0 | 2.1 | 12.6 | 45.0 | 2.5 | 50.0 |
| LIA 512 | 134.0 | 7.55 | 43.1 | 265 | 7 | 9.6 | 55.0 | 2.7 | 17.4 | 20.0 | 1.0 | 1.0 |
| LIA 490 | 134.0 | 5.60 | 42.1 | 201 | 8 | 10.6 | 59.6 | 2.4 | 19.4 | 45.0 | 1.0 | 30.0 |
| Tulvi | 132.6 | 5.20 | 42.2 | 228 | 8 | 9.6 | 59.8 | 2.3 | 14.2 | 60.0 | 2.5 | 37.5 |
| LIA 521 | 132.0 | 6.86 | 42.0 | 221 | 7 | 12,0 | 67.0 | 2.2 | 20.6 | 60.0 | 1.0 | 17.6 |
| LIA 458 | 132.0 | 7.05 | 43.2 | 218 | 8 | 13.4 | 69.6 | 2.7 | 20.0 | 43.0 | 3.3 | 25.0 |
| LIA 395 | 129.7 | 6.10 | 39.5 | 200 | 7.6 | 11.9 | 58.8 | 2.4 | 15.0 | 23.8 | 8.7 | 36.4 |
| LIA 391 | 120.3 | 6.20 | 36.0 | 209 | 6.9 | 10.5 | 60.8 | 2.1 | 17.0 | 19.2 | 3.1 | 20.4 |
| Duoniai | 126.1 | 6.30 | 37.4 | 179 | 7.4 | 10.0 | 62.1 | 2.4 | 9.8 | 18.0 | 11.6 | 14.0 |
| LIA 339 | 125/3 | 6.20 | 37.5 | 196 | 7.2 | 11.9 | 62.6 | 2.4 | 19.9 | 24.9 | 3.5 | 26.4 |
| Joniai | 122.0 | 6.49 | 38.3 | 213 | 7.1 | 10.4 | 62.9 | 2.2 | 12.2 | 21.9 | 14.6 | 17.1 |
| LIA 463 | 122.0 | 6.20 | 37.4 | 218 | 5.4 | 9.4 | 55.1 | 2.3 | 11.5 | 34.0 | 5.0 | 11.9 |
| LIA 489 | 122.0 | 6.00 | 44.2 | 220 | 7.5 | 10.0 | 58.7 | 2.3 | 12.5 | 60.0 | 3.4 | 17.5 |
| LIA 426 | 120.0 | 6.35 | 37.9 | 214 | 6.9 | 10.7 | 64.3 | 2.4 | 10.3 | 18.6 | 8.9 | 14.4 |
| Hacada | 116.8 | 5.90 | 40.4 | 264 | 7 | 9.5 | 56.6 | 2.1 | 11.0 | 35.0 | 2.5 | 0.0 |
| LIA 424 | 113.4 | 5.10 | 35.7 | 219 | 7.6 | 11.2 | 60.8 | 2.0 | 14.4 | 22.3 | 2.5 | 11.1 |
| Motto | 112.4 | 6.10 | 42.6 | 238 | 8 | 9.5 | 55.9 | 2.3 | 9.3 | 40.0 | 5.0 | 12.5 |
| Dominator | 110.1 | 5.30 | 38.0 | 254 | 7 | 9.5 | 55.3 | 2.1 | 13.3 | 50.0 | 5.0 | 12.5 |
| Duktus | 108.9 | 5.20 | 39.8 | 233 | 7.5 | 8.7 | 46.7 | 1.8 | 23.0 | 15.0 | 0.0 | 12.5 |
| LIA 494 | 108.0 | 5.60 | 34.2 | 231 | 7.6 | 11.0 | 59.8 | 2.4 | 18.6 | 9.8 | 3.3 | 12.5 |
| Nikita | 107.9 | 5.20 | 43.5 | 242 | 7.5 | 9.4 | 56.2 | 2.4 | 9.8 | 35.0 | 7.5 | 5.0 |
| J-904-F6 | 107.6 | 5.60 | 40.8 | 262 | 8.5 | 11.9 | 61.0 | 2.2 | 17.1 | 40.0 | 2.5 | 10.0 |
| J-909-F6 | 106.4 | 4.80 | 36.2 | 242 | 8,5 | 11.8 | 58.5 | 1.8 | 21.4 | 40.0 | 5.0 | 25.0 |
| J-92-3F4 | 105.8 | 5.40 | 38.6 | 234 | 9 | 10.9 | 64.6 | 2.2 | 12.5 | 45.0 | 5.0 | 37.5 |
| J-91-1F4 | 105.4 | 4.60 | 37.2 | 255 | 8.5 | 11.3 | 60.3 | 2.1 | 19.7 | 40.0 | 10.0 | 25.0 |
| Rapid | 104.7 | 4.20 | 37.6 | 212 | 6..3 | 9.2 | 56/0 | 2/2 | 11.4 | 40.0 | 5.0 | 12.5 |
| LIA 467 | 105.0 | 5.04 | 37.1 | 214 | 8 | 9.4 | 56.0 | 1.9 | 16.0 | 58.0 | 3.4 | 3.3 |
| Avanti 90 | 100.4 | 5.00 | 40.1 | 284 | 8 | 9.2 | 54.3 | 2.1 | 11.2 | 60.0 | 2.5 | 25.0 |
| Eksprit | 100.1 | 4.90 | 36.2 | 276 | 7.5 | 9.3 | 53.8 | 1.8 | 14.2 | 70.0 | 2.5 | 25.0 |
| Eksprit 90 | 95.0 | 4.40 | 36.5 | 268 | 7,5 | 9.7 | 58.5 | 2.0 | 7.3 | 70.0 | 0.0 | 12.5 |
| Bonopart | 92.3 | 6.00 | 40.0 | 256 | 8 | 9.6 | 58.5 | 2.0 | 10.4 | 52.5 | 2.5 | 30.0 |
| Avanti | 90.1 | 4.80 | 40.6 | 274 | 8.5 | 9.6 | 57.0 | 2.2 | 9.8 | 50.0 | 5.0 | 25.0 |
| Kaselot | 90.5 | 3.70 | 34.5 | 229 | 8 | 9.7 | 56.3 | 1.9 | 16.5 | 45.0 | 0.0 | 12.5 |
| Piccas 90 | 89.9 | 3.40 | 33.8 | 277 | 7 | 8.9 | 51.2 | 1.5 | 20.4 | 40.0 | 0.0 | 5.0 |
| Enrico | 88.5 | 3.90 | 37.0 | 247 | 7.5 | 8.5 | 51.8 | 2.2 | 16.7 | 35.0 | 0.0 | 5.0 |
| SwHy96 | 86.1 | 5.00 | 38.1 | 264 | 8.5 | 10.1 | 59.7 | 2.3 | 12.5 | 40.0 | 0.0 | 12.5 |
| Avanti 30 | 85.8 | 3.10 | 35.5 | 283 | 7 | 9.0 | 51.8 | 1.7 | 11.6 | 60.0 | 0.0 | 12.5 |
| Piccaso | 83.9 | 4.10 | 38.0 | 317 | 8.5 | 9.2 | 59.1 | 2.2 | 8.1 | 50.0 | 0.0 | 5.0 |

lity undesirable for bread-making industry [8]. The rye varieties grown in East Europe, where growing conditions in summer and autumn are dry and rapid germination is important, are characterized by more active amylases [9]. The regression between stem height and the Falling Number index, which indirectly indicates the activity of amylases, was found to be negative XY = 0.741, $R^2$ = 0.548, Ft = 46.14 ($P < 0.01$). For a long time Lithuanian rye breeding has been focused on the improvement of protein content. It was found that protein content negatively correlated with amylase activity [9]. As a result of previous breeding efforts, the local rye genotypes are characterized by a lower Falling Number index. For the future rye breeding programs it is important to include genotypes from West European countries with a low activity of amylases in grain. The influence of stem height on grain protein and starch content and test weight was not significant.

During the experimental years the incidence of leaf rust was high and fluctuated in rye varieties and lines from 9.8 % to 70.0%. The varieties with taller stems were found to be more resistant to brown rust, but the correlation between these parameters was not significant. The varieties and lines of Lithuanian origin (especially LIA 494) were less susceptible to brown rust, the average incidence being 37.5%, while for the other varieties the brown rust incidence

Table 2. **Pared regression between plant height (*x*) and other traits (*y*) of winter rye**

| Trait | Correlation Index (XY) | Fisher's test | $R^2$ | $\overline{X} \pm S_e$ | Equation of a regression y(x) = a + bx |
|---|---|---|---|---|---|
| Grain yield | 0.829 | 83.38** | 0.687 | 5.43 ± 0.17 | y = –0.33 + 0.052 x |
| 1000 grain weight | 0.359 | 5.61* | 0.128 | 38.6 ± 0.44 | y = 31.97 + 0.059 x |
| Plant lodging | 0.436 | 8.9** | 0.190 | 112.1 ± 2.62 | y = 9.794–0.020 x |
| Falling Number index | –0.741 | 46.14** | 0.548 | 235 ± 5.13 | y = 398.10–1.450 x |
| Protein content | –0.253 | not significant | | 12.43 ±0.14 | |
| Starch content | –0.192 | not significant | | 57.96 ±1.38 | |
| Test weight | 0.147 | not significant | | 725.8 ±7.80 | |
| Spike length | 0.475 | 11.05** | 0.225 | 10.19 ± 0.18 | y =6.622 + 0.032 x |
| Number of spikelets per spike | 0.554 | 16.87** | 0.307 | 34.40 ± 0.55 | y = 21.878 + 0.113 x |
| Grain number per spike | 0.473 | 10.98** | 0.224 | 58.33 ± 0.71 | y = 44.241 + 0.127 x |
| Grain weight per spike | 0.556 | 17** | 0.309 | 5.16 ± 0.04 | y = 1.239 + 0.008 x |
| Grain weight per plant | 0.433 | 8.78** | 0.187 | 15.79 ± 0.53 | y = 9.249 + 0.058 x |
| Per cent of empty spikelets | 0.326 | 4.51* | 0.106 | 14.81 ± 0.67 | y = 5.385 + 0.083 x |
| Brown rust | 0.385 | 6.61* | 0.148 | 40.07 ± 2.52 | y = 81.027–0370 x |
| Stem rust | 0.322 | 4.4* | 0.104 | 3.85 ± 0.50 | y = –3.236 + 0.065 x |
| Powdery mildew | 0.280 | not significant | | 17.39 ±1.79 | |

* $P < 0.05$.
** $P < 0.01$.

amounted to 43.2%. The same authors report that the lines of rye are more resistant to the local leaf rust population [10]. Short stem rye varieties are more susceptible to leaf rust, and this disease can cause a yield reduction of 21–39% [11]. Leaf rust resistance of the varieties is controlled by different oligogenes [12].

The incidence of stem rust and powdery mildew was lower and ranged from 1.0 to 14.6% and from 1.0 to 50.0%, respectively. Tall-growing varieties and lines of rye were subject to a higher occurrence of stem rust, whereas the varieties with the shortest stems were free from this infection. No correlation and trends were found between rye height and the incidence of powdery mildew.

The main reasons why tall winter rye cultivation was discontinued were its low lodging resistance and low grain yield. In our investigations, we found that the grain yield in general tended to negatively correlate with plant lodging, too, but the correlation was not significant (0.298), $R^2$ = 0.089, Ft = 3.69 (Table 2), indicating that among tall-growing varieties it is possible to select proper material with acceptable lodging resistance, especially that the possibility to earn benefit in yield is much higher. Analysis of the accessions studied showed that among the tallest (>130 cm) only three varieties were more susceptible to plant lodging (Table 1). The variety 'Tulvi'and lines LIA 512, LIA 490, LIA 521, LIA 458, LIA 395 were estimated by 7–8 scores. The grain yield of these accessions was 5.20, 7.55, 5.60, 6.86, 7.05, 6.10 t/ha$^{-1}$, respectively, the Falling Number index indicating grain quality being more than 200 s. It can be concluded that the most valuable genetic resource for further breeding programmes among the accessions tested could be lines LIA 512, LIA 521 and LIA 458, which are the highest yielding and characterised by high grain quality and tolerance of plant diseases.

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**AUKšTASTIEBIØ RUGIØ GENETINË MEDÞIAGA VEISLIØ PAGERINIMUI**

Santrauka

Ðiø tyrimø tikslas buvo iðtirti aukðtastiebiø bei þemastiebiø rugiø savybes ir nustatyti, ar aukðtastiebiai rugiai gali bûti naudojami kaip genetinis ðaltinis naujø rugiø veisliø selekcijos programoms. Lauko bandymai buvo atlikti Lietuvos þemdirbystës institute 2002–2004 metais. Buvo tiriama 21 veislë bei 19 naujø rinktiniø selekciniø linijø, sukurtø instituto augalø selekcijos centre. Tyrimais nustatyta, kad aukðtastiebiai rugiai yra vertingas naujø veisliø pagerinimo genetinis ðaltinis. Porinë regresinë analizë rodo teigiamà ryðá tarp augalø ($R^2$ = 0,687). Su augalø aukðèiu susijæ svarbûs biologiniai rodikliai: varpuèiø skaièius varpoje, grûdø skaièius varpoje, varpos grûdø svoris, 1000 grûdø masë, augalo grûdø svoris. Aukðtesni augalai uþaugina ilgesnes varpas, taèiau jose bûna daugiau tuðèiø varpuèiø. Nustatytas neigiamas ryðys tarp augalø aukðèio ir amilaziø aktyvumo ($R^2$ = 0,548). Aukðtesni rugiai maþiau jautrûs rudosioms rûdims ir miltligei, taèiau labiau – augalø iðgulimui. Nustatyta neigiama priklausomybë tarp grûdø derliaus ir iðgulimo, taèiau ðis ryðys nepatikimas. Rezultatai rodo, kad tarp aukðtastiebiø rugiø veisliø galima rasti vertingos genetinës medþiagos naujø veisliø kûrimui. Tarp tirtø paèiø aukðèiausiø veisliø (> 130 cm) tik trijø veisliø iðgulimas buvo ávertintas maþesniu uþ 7 balu. Pakankamai atspari veislë ‘Tulvi’ bei LIA 512, LIA 490, LIA 521, LIA 458, LIA 395 linijos, kuriø derlingumas buvo atitinkamai 5,20, 7,55, 5,60, 6,86, 7,05, 6,10 t $ha^{-1}$. Kaip genetinis naujø veisliø kûrimo ðaltinis ypaè vertingos yra LIA 512, LIA 521, LIA 458 linijos, pasiþymëjusios didþiausiu grûdø derliumi, kokybe ir atsparumu ligoms.