Influence of subterraneous plant organs on yields and winter hardness of winter triticale (× Triticosecale Wittm.)

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Abstract. Purpose of this work was to identify the influence of the underground part of the plant on winter hardness and crop yields of collection of winter hexaploid triticale with different eco-geographical origin in the terms of Nonchernozem zone in Russia. The set of 43 hybrids of triticale with different eco-geographical origin was divided into 5 groups according to its origin: Dagestan, North Caucasus, Central Black Earth zone and Ukraine, Nonchernozem zone of Russia, Belarus and Eastern Europe. For every hybrid in a group, the number of plants with lower tillering node, availability and degree of epicotyl development and secondary root system calculated and the correlation analysis of these traits with grain yields performed. The grain yields considered as an integral indicator of the genotype adaptability for specific environment conditions. As a result, the triticale genotypes with stable development of a large number of plants with lower tillering node selected Mikola, Antey, Valentin, AD4, Timbo, AD44 and Flamingo. The influence of environment conditions where the triticale hybrid created on selection of high yields genotype and increased number of plants with lower tillering node revealed. Greatest conjugacy between crop yields and availability of double tillering nodes is typical for hybrids from Central part of country and Belarus. It turned out that hybrids from southern regions have a positive relation of crop yields and the length of epicotyl. The hybrids from Central part of Russia, Belarus and Europe do not have this correlation. A weak positive relation in triticale hybrids found between development of secondary root system and grain yield.

1. Introduction

Winter hardness is one of the most important adaptive properties of winter crops affecting the yields. The level of winter hardness of triticale has an intermediate value versus parental species. The climate and environmental conditions of region influence on the triticale winter hardness [1;5;8;10;14;16]. The main reasons for the winter triticale destruction in the Central Region of the Nonchernozem zone of Russia are low temperatures and damage to plants by snow mold. The disease is caused by low-temperature fungi of the genera \textit{Typhula} and \textit{Fusarium}, which grow under snow with a high snow cover and lasting (more than 3 months) stay of plants under the snow. Triticale plants tolerate low temperatures well, but have no tolerance to snow mold [5;8;14;16]. They die as a result of damage to the overground part and the growth point situated in the tillering node. If the growth point preserves then triticale is able to restore the density [6;9].
In CRNZ (Central Region of Nonchernozem zone) the usual seeding depth on loamy soil is 5 cm. While seeds sprouting, at first the primary root system is first formed, the coleoptile is stretched which is a leaf consisting only of a leaf sheath. Then the first leaf with a leaf blade passes through it. Later what happens is a strong elongation of the internode located between the node of the coleoptile and the first real leaf. This internode is called root-shaped due to its strong resemblance to the root or epicotyl. Its function is to move the node with the leaf closer to the soil surface. In this node, a system of new overground shoots is formed, the combination of which forms the primary tillering node. The secondary root system is also formed here [13]. Cereal crops usually have one primary tillering node, which is located at a depth of 1.5-2 cm, which makes it vulnerable to low temperatures or other factors. The death of the tillering node leads to the death of the plant.

Some plants have an additional tillering node which can be formed from the axillary bud of the coleoptile, located at the depth of seed embedding. This node can be a reserve for the preservation of plants in the winter season when the main tillering node dies [11;13]. As for winter wheat, normal productive shoots develop from such nodes, which can provide up to 50% of the yield [7;15;17].

The causes why the double tillering nodes appear in cereals are not well studied. It is unclear whether this ability is driven by the genotype or it is a modification linked with different depth of seeds placement, lighting conditions, temperature, soil moisture, etc. Attempts were made to select winter wheat and barley to create winter-resistant varieties having two tillering nodes [3-4;15]. Varieties of winter wheat and barley varieties with high winter hardness, having 60-100% of plants with a double tillering node have already developed [3-4;18]. Regarding triticale, the correlation between the double tillering node and agronomic characters and properties nowadays has not yet been studied.

The objective of research was to identify the influence of the underground part of the plant on the yield and winter hardness of the collection of winter hexaploid triticale with different eco-geographical origin in the terms of Nonchernozem zone in Russia.

Evaluation of the collection and selection of genotypes of winter triticale with elevated number of double tillering nodes could have a great practical importance for creating varieties with increased winter hardness.

2. Materials and methods
The research covers 43 samples of winter hexaploid triticale of various ecological and geographical origin. For the analysis, the variety samples were grouped by regions with relatively similar natural and climatic conditions for which they were created (table 1). Dagestan belongs to the North Caucasus region, but it was decided to form a special group consisting of the varieties of the Dagestan experimental station. Finally, there were 5 groups of variety samples developed for specific growing conditions.

The study was carried out at the Department of Genetics, Breeding and Seed Production of RGAU-Moscow Agricultural Academy named after K.A. Timiryazev in 2014-2017. The field experiments were placed at the Breeding station named after P.I. Lisitsyn. Agricultural technology is adopted for this zone. The registered area of plot is 1m², the repetition is three-fold, the placement is systematic. Sowing with a selective cassette seeder in late August - early September, manual harvesting.

After tillering phase, the plants of second row on the plot (on average 50pcs) were dug out, the underground part was washed to evaluate the presence of lower tillering node and root-like internode (epicotyl). The length of the epicotyl and roots was measured. In the spring, overwintering was evaluated on a 5-point scale (5 points – no noticeable damage, 1 – single plants survived, 2, 3, 4 points – an intermediate state) [12].

After threshing the sheaves on the MPSU-500 sheaf thresher, the grain yield was evaluated. Statistical processing of the results was carried out according to generally accepted methods [2] using the AGROS program. The data expressed as a percentage was converted to an angle-arcsine.

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**Table 1.** The origin of triticale hybrids/varieties.

| Grades name | Place of origin | Groups similar by natural and climatic conditions |
|-------------|-----------------|-------------------------------------------------|
| PRAG 509, PRAG 489, PRAG 468, PRAG-S-230/3, Soyuz × 531h, 563h, PRAG 530, PRAG 341, PRAG 152, PRAG 531 × PRAG473 Tornado, Bard, Konsul, Legion, Vokaliz | Dagestan experimental station VIR (All-Russian Institute for Plant Genetic Resources) | Dagestan experimental station VIR (All-Russian Institute for Plant Genetic Resources) |
| KNIISKH 32, Valentin 90, Kaskad | Don zonal Scientific research Institute of agriculture | North Caucasian region |
| Kvaraz | Named after P.P. Luk'yanenko Stavropol Agricultural Research Institute | |
| Viktor, Nemchinovskii 56, Germes, Antei, Valentin | Moscow Agricultural Research Institute "Nemchinovka" Russian State Agrarian University-Moscow Timiryazev Agricultural Academy named after K.A. Timiryazev | Central region of Nonchernozem zone (CRNZ)of Russia and Belarus |
| Dubrava, Adas', Mara, Mikola, Liniya 19, Liniya 96, Doktrina 110, ADP 256, AD 44, TPG-10-79, Ladne, Flamingo, Polesskii 10, Hewo, Yanko, RAH, Triskell, Timbo | Voronezh | Central Black Earth region and Ukraine |
| AD 4 | Ukraine | |
| | Poland | |
| | France | Eastern Europe |

The data on the meteorological conditions of the years of the experiment and the height of the snow cover were kindly provided by the V.A. Mikhelson Meteorological Observatory.

3. Results and Discussion

The conditions for overwintering triticale plants that developed in the winter of 2014-2015 were favorable (figure 1).

The snow cover was constantly increasing during the winter period with moderate negative temperatures. In the spring, the snow melted away by the second decade of April. Triticale plants were under the snow for 4 months and 10 days.

The conditions of overwintering of plants in the period of 2015-2016 were unfavorable, which resulting in the death of plants of some variety samples. In autumn, the snow cover was established early at a positive temperature. The winter period was characterized by regular thaws, which led to a change in the height of the snow cover. In the spring, the snow melted down by the beginning of April. The plants were under snow for 4 months and 20 days.

The conditions for overwintering triticale plants in 2016-2017 were relatively favorable. The snow cover was established above 20 cm at moderately low temperatures and persisted for 4 months and 20 days. The average daily temperature did not fall below -15 °C.

The ability of winter crops to survive the winter period is the basis for maintaining the planned density of crops, and, as a result, the grain harvest. The studied variety samples of triticale; were distinguished by good winter hardiness (with the exception of the southern varieties Quasar, PRAG
531×PRAG473 and Triskell). Due to the death of most of the plants, these varieties had low productivity. The plants remaining on the plots, due to the large area of nutrition, constantly formed new shoots. However, their increased tilling capacity did not compensate for the loss of some plants (table 2).

![Figure 1. Environmental conditions of the winter period, 2014-2017.](image)

Variety samples of triticale differed in the content of plants with a lower tillering node. Besides, the same varieties in different years contained different number of plants with two nodes.

The variety samples were selected which consistently form a large number of plants with lower tillering nodes over the years: Mikola, Antey, Valentin, AD 4, Timbo, AD 44 and Flamingo. Since among the majority of varieties it was found few such plants in the sowing, it is possible to assume the genetic determination of this trait. This question requires further examination because a limited set of variety samples was used in our study.

Taking together, for the whole set of varieties, a tendency towards a positive effect of an increased content of plants with double tillering nodes on yield was revealed (figure 2). This prescribes the selection of winter-hardy forms of triticale with a high content of plants with double knots.

At the same time the correlation between the number of plants with double tillering node and the yield was determinant by the geographical area where the hybrid was developed. Thus, the variety samples from Dagestan in total did not show the correlation between the yield and presence of plants with double tillering node (figure 2). The variety samples of North Caucasus region in general demonstrated a weak trend to the yield increase at the varieties having the plants with double tillering nodes.
Table 2. Crop yields and elements of underground plant parts of triticale, average for the period 2015-2017.

| Place of origin | Hybrid | Crop yields, t/ha | Number of plants with lower tillering node, % | Length of, cm epicotyl, % | Length of, cm epicotyls roots |
|-----------------|--------|-------------------|-----------------------------------------------|-------------------------|--------------------------------|
| Dagestan experimental station VIR (All-Russian Institute for Plant Genetic Resources) | PRAG 509 | 7.10 | 0.99 | 95.4 | 1.5 | 9.3 |
| | PRAG 489 | 7.44 | 7.66 | 94.2 | 1.5 | 9.1 |
| | PRAG 468 | 5.99 | 10.00 | 94.4 | 1.4 | 8.8 |
| | PRAG-S-230/3 | 6.70 | 2.99 | 92.3 | 1.4 | 9.2 |
| | Soyuz × 531h | 5.20 | 0.52 | 83.3 | 1.4 | 8.9 |
| | 563h | 6.18 | 4.77 | 90.2 | 1.4 | 8.9 |
| | PRAG 530 | 5.50 | 6.01 | 93.4 | 1.4 | 9.2 |
| | PRAG 341 | 5.99 | 10.00 | 94.4 | 1.4 | 8.8 |
| | PRAG 152 | 6.87 | 5.26 | 92.8 | 1.4 | 9.2 |
| | PRAG531×PRAG473 | 6.01 | 20.72 | 94.7 | 1.6 | 9.3 |
| North Caucasian region | Group average | 6.38 | 6.58 | 91.6 | 1.4 | 16.9 |
| | Tornado | 6.71 | 8.07 | 89.7 | 1.4 | 9.4 |
| | Bard | 8.18 | 3.18 | 90.9 | 1.3 | 8.0 |
| | Konsul | 8.10 | 2.08 | 88.3 | 1.4 | 9.1 |
| | Legion | 8.65 | 9.10 | 94.0 | 1.5 | 9.2 |
| | Vokaliz | 9.51 | 6.66 | 92.1 | 1.7 | 8.7 |
| | Kvazar | 4.80 | 5.66 | 92.7 | 1.5 | 9.5 |
| | KNIISKh 32 | 6.25 | 1.37 | 80.3 | 1.3 | 9.2 |
| | Valentin 90 | 8.18 | 13.59 | 91.2 | 1.6 | 8.4 |
| | Cascade | 7.88 | 3.82 | 95.3 | 1.9 | 9.0 |
| | Group average | 7.58 | 5.96 | 89.1 | 1.5 | 9.0 |
| | Viktor | 7.67 | 3.22 | 95.3 | 1.9 | 9.0 |
| Central region of Nonchernozem zone (CRNZ) of Russia and Belarus | Nemchinovskii 56 | 8.31 | 7.26 | 87.1 | 1.3 | 9.3 |
| | Germes | 7.22 | 3.82 | 91.7 | 1.5 | 8.4 |
| | Antel | 9.40 | 13.71 | 95.0 | 1.6 | 9.3 |
| | Valentin | 7.41 | 13.16 | 88.3 | 1.4 | 8.6 |
| | Dubrava | 6.38 | 6.39 | 94.6 | 1.9 | 8.9 |
| | Asa | 7.38 | 2.30 | 89.2 | 1.5 | 9.2 |
| | Mara | 7.11 | 3.37 | 85.6 | 1.5 | 10.3 |
| | Mikola | 9.01 | 21.48 | 89.3 | 1.3 | 9.2 |
| | Group average | 7.76 | 8.30 | 90.7 | 1.5 | 9.1 |
| | Liniya 19 | 7.56 | 12.21 | 94.2 | 1.7 | 8.1 |
| | Liniya 96 | 7.36 | 10.00 | 94.8 | 1.4 | 9.6 |
| | Doktrina 110 | 8.27 | 8.30 | 92.2 | 1.6 | 9.2 |
| | ADP 256 | 8.58 | 6.73 | 95.6 | 1.7 | 9.6 |
| | AD 44 | 7.01 | 15.78 | 94.9 | 1.6 | 9.1 |
| | TPG 10-79 | 6.09 | 12.72 | 91.5 | 1.5 | 8.9 |
| | Ladne | 7.40 | 9.70 | 79.6 | 1.3 | 10.1 |
| | Flamingo | 7.11 | 17.36 | 90.9 | 1.4 | 8.9 |
| | Polesskii 10 | 7.51 | 4.46 | 94.1 | 1.3 | 9.5 |
| | Group average | 7.43 | 10.81 | 92.0 | 1.5 | 9.2 |
| | Hewo | 8.50 | 3.93 | 94.0 | 1.4 | 9.3 |
| | Yanko | 7.78 | 1.57 | 89.8 | 1.3 | 8.5 |
| | RAH121/94 | 7.37 | 6.60 | 90.9 | 1.3 | 9.0 |
| | Triskell | 6.62 | 11.22 | 99.1 | 1.7 | 8.8 |
| | Timbo | 7.24 | 18.77 | 97.0 | 1.7 | 9.4 |
| | AD 4 | 8.27 | 34.20 | 92.8 | 1.5 | 9.6 |
| | Group average | 7.63 | 12.72 | 93.9 | 1.5 | 9.1 |
| | LSD05 | 2.18 | 6.67 | 11.6 | 0.5 | 1.7 |
The variety samples from Central Black Earth Region, Ukraine and Europe did not show any connection between these indicators. On the other hand, the samples developed in the Middle zone of the Russian Federation and the Republic of Belarus showed a stable positive trend in yield depending from the number of plants with double tillering nodes, both in particular years and on average over the years. This indicates that during the creation of these varieties, an unconscious selection of forms with an increased number of the lower tillering nodes was carried out, which ensured a better overwintering of plants. In regions where the winter period is not so severe, selection by conjugate traits has not been identified.

Most often, the lower tillering node was formed in the variety samples developed in the Central Part of Nonchernozem Zone, Central Black Earth Region, Poland and Moldova.

In the course of the study, it was revealed that the majority of triticale plants formed epicotyls. However, there were samples with a reduced number of plants that formed an epicotyl (table 2).

The varieties created in the southern regions showed a positive correlation between the plant content with epicotyl and its size with the yield level. The European samples showed a negative dependence, and the samples of the middle zone of the Russian Federation did not show a certain dependence. A possible reason for such results is that in the southern regions of our country, winter crops are often sown to a great depth (10 cm) due to the lack of precipitation and strong drying out of the arable layer [6]. Therefore, when creating varieties adapted to such conditions, they unconsciously selected genotypes that form long epicotyls. For Europe and central Russia, this problem is not relevant.

In general, for the studied set of variety samples, we can note a certain positive trend of increasing yield with increasing epicotyl length. This is probably due to the predominance of the number of southern varieties in the set under research.

Evaluation of the influence of root development of triticale plants on yield showed that in most cases it has positive impact (figure 3).

Only in the samples created for the North Caucasian region this influence was not revealed. In general, based on the previous experience, it was also not found. Perhaps such results can be explained by the fact that the studies were conducted in an area atypical for southern varieties. Or, it is possible
that the yield is influenced by the degree of development of the primary root system, which was not taken into account in our research.

![Correlation with the length of secondary roots and grain yield, average for 2015-2017.](image)

4. Conclusion
It was identified the influence of the ecological conditions where the triticale hybrids were created, on selection of high yields genotypes and increased number of plants with lower tillering nodes. The small positive dependence between development of secondary root system of triticale hybrids and grain yield revealed. The triticale genotypes with stable development of a large number of plants with lower tillering node selected Mikola, Antey, Valentin, AD4, Timbo, AD 44 and Flamingo. The ecological conditions of varieties place of origin have influence on selection of triticale genotypes with availability of long epicotyl. The positive correlation with yield and this criterion for hybrids of South Region revealed. Whereas no correlation for the hybrids of Central Russia, Belarus and Eastern Europe.

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