Diversification of winter grain crops in the middle Volga region of Russia

Sergey Shevchenko¹, Alexey Bisharev¹, Sergey Zudilin¹

¹Samara State Agricultural University, Uchebnaya str., 1, 446442, Ust'-Kinelskiy, Samarskaya obl., Russia
E-mail: zudilin_sn@mail.ru

Abstract. To determine the prospects for the use of new winter crops (triticale, barley) in addition to traditional crops (winter wheat and winter rye) in order to diversify the winter wedge, studies were conducted on the basis of the Samara Research Institute of Agriculture and the Samara State Agricultural Academy from 2004 to 2018. Weather conditions over the years of study were characterized by high contrast. The effect of various ratios of wheat and triticale flour on the quality of bread was studied. When conducting test baking, the best quality bread is obtained from a mixture: wheat flour 50% and triticale flour 50%. As a result of breeding work, two varieties of winter triticale Krokha, Kapella are zoned, and two varieties (Spica, Arktur) are in the state variety test. It has been established that the limiting factor affecting the formation of the yield of winter barley grain in the Middle Volga region is the low temperature at the depth of the tillering node. The years are determined, characterized by favorable and unfavorable conditions for the wintering of winter barley. The best for wintering in the Middle Volga region is a variety of winter barley Zhiguli. When fertilizer was applied, winter barley formed a higher yield (2.03...4.80 t/ha) compared to winter wheat and triticale.

1. Introduction

The Middle Volga region is one of the largest grain producers in Russia. Volga conditions allow annually receiving high gross harvests of grain and other agricultural products. However, obtaining such yields is constrained not only by a lack of moisture, but also by the low stability of the phytosanitary state of crops [1, 2, 3].

Winter rye in the Middle Volga region has long been considered the most important food crop. Winter rye is a highly winter-resistant, plastic and adaptive grain crop of strategic importance. However, in recent decades there has been a sharp reduction in the sown areas of winter rye [4]. So at the beginning of the 20th century, winter wheat was not widespread for a number of reasons, and now it occupies significant areas. This is primarily due, of course, to the achievements of breeding and climate change. Currently, due to global warming, there has been a tendency to increase air temperature. It has been established that the average annual air temperature in the Samara region over the past 31 years has increased by 1.4 °C. This is fully consistent with the analysis of changes in climatic conditions in the Middle Volga region [5]. Of the periods of the year, temperature increases in the winter months. There was a shift in climatic conditions conducive to the cultivation of winter crops.

Feed and processing industries need raw materials for baking, production of feed, alcohol, and starch. In solving this problem, the diversification of winter crops, that is, the targeted cultivation of a...
particular crop for a specific purpose, is relevant. In recent years, there has been a gradual expansion of cultivated areas for crops such as winter triticale and winter barley, which until recently were considered exotic.

Barley, sown areas in the world is inferior only to wheat, rapeseed and corn. Agricultural producers cultivate barley mainly for livestock breeding, since grain, in comparison with other crops, has a better protein balance, including the main essential amino acids [6, 7, 8, 9, 10]. The grain yield of winter triticale and barley is not inferior to traditional crops such as rye and wheat (Table 1).

Table 1. Grain yield of winter crops, Samara Research Institute of Agriculture.

| Culture         | 2014 | 2015 | 2016 | 2017 | 2018 | average |
|-----------------|------|------|------|------|------|---------|
| Winter rye      | 46.1 | 25.4 | 55.2 | 73.3 | 37.6 | 47.5    |
| Winter wheat    | 44.8 | 39.4 | 56.1 | 65.2 | 32.7 | 47.6    |
| Winter triticale| 36.6 | 19.8 | 64.9 | 69.2 | 30.8 | 44.3    |
| Winter barley   | 28.7 | 16.4 | 73.9 | 42.3 | 22.9 | 36.8    |

Against the backdrop of gradually increasing economic and environmental problems, there are all reasons to believe that the role of these crops in the Middle Volga region will increase in the future. In favor of economic feasibility of expanding the crops of triticale and barley, there are circumstances such as:

- relative low cost of grain;
- suitability for cultivation in crop rotations saturated with grain crops;
- the emergence of new high-yielding winter hardness varieties of the special purpose.

Triticale is a new grain crop characterized by a large yield potential, a high protein content, essential amino acids (lysine, tryptophan). This determines its nutritional and feed benefits. The protein content is 1-1.5% higher than wheat and 3-4% higher than rye. Gluten content is 3-4% higher than wheat, but lower quality.

Barley is a leading grain crop in the Russian Federation. Winter barley has a number of advantages compared to spring barley and other crops. He uses the reserves of productive moisture in the soil in the autumn-winter period better than others and is able to escape from the harmful effects of drought in the summer period. In this regard, it is capable of producing a grain yield that exceeds on average 1.6 times the yield of spring barley, and in some years 1.9-3.0 times (Figure 1).

Figure 1. Comparative productivity of winter and spring barley.
2. Material and methods

Studies were carried out on the basis of the N.M. Tulaykov Samara Research Institute and Samara State Agricultural Academy from 2004 to 2018.

Analysis of precipitation from 2004 to 2018 showed that 2010 was the driest year of observation. During the period from April to July, 25.0% of precipitation fell from the long-term average values, and the average air temperature was 3-4 ºС higher than normal.

In 2005 and 2010, an autumn drought was observed. From August to September, precipitation fell 59.7-65.7 mm less than the average annual values, which affected the decrease in productive moisture reserves in the arable layer of the soil to 11-18 mm. This had an extremely negative effect on field germination, growth and development of winter crops.

Satisfactory conditions for growth and development were characterized in 2007, 2008 and 2009. Summer vegetation of plants took place with an uneven distribution of precipitation throughout the entire period.

The most favorable weather conditions during the spring-summer vegetation were in 2005, 2011, 2013, 2014, 2015, 2016, 2017. The average monthly precipitation in June exceeded the annual average value from 16.0% to 112.9%, which contributed to the formation of a high grain yield.

Overwintering conditions over the years of research were different. Favorable for overwintering were 2003/2004, 2004/2005, 2006/2007, 2007/2008, 2013/2014, 2015/2016, 2016/2017. The temperature at the depth of the tillering node during the overwintering period did not fall below -7.1 ºС. The most stringent conditions for overwintering developed in 2009/2010, 2012/2013. The temperature at the depth of the tillering node dropped to -12.0...-16.4 ºС.

The objects of research were varieties of winter rye, winter wheat, winter triticale and winter barley in the nursery of competitive variety testing. Bookmark nurseries of competitive and environmental variety testing were carried out with the Klen-1.5S seeder. The accounting area of the plots is 20 m², in four multiple repetitions, the location of the plots is randomized. Agricultural technology was common for the zone. The sowing rate of 4.5 million germinating seeds per hectare. Harvesting was carried out by the Sampo-130 combine. The experimental work was carried out in accordance with generally accepted methodological recommendations [11, 12, 13]. In the Samara State Agricultural Academy, the possibility of obtaining the planned grain yield of winter crops of 2.8 and 3.3 t/ha, provided with moisture resources, after oilseed radish cultivated on green mass in cropped and green-manured fallows was studied. Control sample was without fertilizing. Statistical processing of experimental data was carried out using the Agros 2.0 application software package.

3. Results and discussions

Triticale is important as a grain-feed crop, the feed quality of which is superior to wheat, barley and rye in a number of indicators. Selection of winter triticale in the Samara Research Institute of Agriculture was launched in 1996. In accordance with the adopted program, the creation of varieties of two types of grain feed and grain direction is carried out. Work on winter triticale is carried out jointly by the Moscow Research Institute of Agriculture, the Research Institute of Agriculture of the South-East, the Krasnodar Research Institute of Agriculture, the Don Research Institute of Agriculture and with the involvement of the Research Institute of Plant Industry collection as source material. To create selection material, we use the hybridization method within the framework of hexaploid triticale based on the application of the achievements of world and our own selection. The main tasks of winter triticale selection are currently:

- increase winter hardiness and drought tolerance;
- the creation of highly productive varieties of intensive and semi-intensive type resistant to biotic stresses;
- the creation of varieties with high quality grain for special purposes.

Triticale grain can be used not only as a concentrated feed for animals, but also in bakery and confectionery industries. However, the baking quality of triticale is lower than that of wheat. In this connection, we studied the effect of various ratios of wheat and triticale flour during baking. As a
result of test baking, the best quality bread is obtained from a mixture: wheat flour 50% and triticale flour 50% (Table 2).

Table 2. Quality indicators of test bread baking depending on the ratio of wheat and triticale flour.

| Ratio               | Shape | Peel color | Porosity | Taste | Bread volume, cm³ |
|---------------------|-------|------------|----------|-------|-------------------|
| Wheat flour         | 3.5   | 4.0        | 4.5      | 4.0   | 665               |
| Triticale flour     | 3.0   | 3.0        | 4.5      | 4.0   | 465               |
| 70:30 (triticale)   | 4.0   | 4.0        | 4.0      | 4.0   | 720               |
| 50:50 (triticale)   | 4.5   | 4.5        | 5.0      | 4.5   | 785               |
| 15:85 (triticale)   | 3.0   | 3.0        | 4.0      | 4.0   | 395               |

As a result of the selection work carried out in the Samara Research Institute of Agriculture, two varieties of winter triticale Krokha, Kapella are zoned and two varieties Spika, Arktur are in the state variety test.

The Krokha variety was created jointly by the Samara Research Institute of Agriculture and the Krasnodar Research Institute of Agriculture. It has been included in the State Register of Breeding Achievements of the Russian Federation since 2014. It is designed for cultivation for fodder and food purposes. It forms increased density of productive stalk (441 st./m²) (Table 3). The average yield is 46.6 c/ha. The protein content in the grain is 12.8%. The volume of bread is 308 cm³ from 100 g of flour. It is characterized by high winter hardiness and resistance to droughty conditions of the Middle Volga region.

Table 3. Characterization of the economic and biological features of winter triticale varieties in the competitive variety testing, Samara Research Institute of Agriculture, 2015-2017.

| Parameters                        | Unit of Measure | Krokha | Kapella | Arktur | Spika |
|-----------------------------------|-----------------|--------|---------|--------|-------|
| Grain harvest                     | c/ha            | 46.6   | 50.5    | 56.5   | 52.6  |
| Plant height                      | cm              | 103.0  | 148     | 89.2   | 115   |
| Resistance to lodging             | score           | 8.6    | 7.3     | 9.0    | 8.3   |
| Length of the vegetation period   | days            | 296    | 293     | 294    | 294   |
| Weight of 1000 grains             | g               | 33.5   | 43.4    | 42.3   | 41.5  |
| Grain unit                        | g/l             | 667    | 713     | 679    | 668   |
| Glassiness                        | %               | 46.7   | 47.7    | 42.6   | 36.2  |
| Grain protein content             | %               | 12.8   | 12.8    | 13.8   | 13.3  |
| Amylogram height                  | units           | 100    | 126     | 177    | 257   |
| Fall number                       | sec.            | 94     | 85      | 184    | 223   |
| Density of the productive stalk   | pcs             | 441    | 423     | 393    | 472   |
| Brown rust damage                 |                 | 30     | 0       | 5-15   | 0     |
| Number of grains in the ear       | pcs             | 42.0   | 36.2    | 42.9   | 37.0  |
| Volumetric yield of bread         | ml              | 308    | 328     | 438    | 445   |

The Kapella variety was created jointly by the Samara Research Institute of Agriculture and the Moscow Research Institute of Agriculture “Nemchinovka”. It has been included in the State Register of Breeding Achievements of the Russian Federation since 2019. It is characterized by high winter hardiness and resistance to droughty conditions of the Middle Volga region, does not crumble, and is well threshed. The variety is intended for cultivation on fodder. The weight of 1000 grains is 43.4 g. The average yield is 50.5 c/ha. The protein content in the grain is 12.8%. Over the years of testing, the variety was not affected by powdery mildew and brown rust. A distinctive feature: during the ripening phase, it retains the photosynthetic activity of the stem, spike and leaves, which ensures the production of large and coarse grains.

Variety Arktur was created jointly by the Samara Research Institute of Agriculture and the Moscow Research Institute of Agriculture “Nemchinovka”. Winter hardiness is above the standard of the Krokha variety. The growing season is 294 days, 2 days shorter than the standard. Resistance to lodging is 9 scores. In some years, the variety is not significantly affected by brown rust of 5-15%.
The variety is characterized by high agroecological adaptability. The average yield for 2015-2017 amounted to 56.5 kg/ha, which is 9.9 kg/ha higher than the standard of the Krokha variety. It is steady against germination of grain in an ear. It is recommended for production in the Middle Volga region for food purposes.

Variety Spica is characterized by high winter hardiness and droughty tolerance. The growing season is 294 days, 2 days shorter than the standard. Resistance to lodging is 8-9 scores. The ear is productive, well-grained (the number of grains is 37.0 pcs). The density of the productive stalk was 472 st./m², higher by 31 st./m² than the standard. The weight of 1000 grains is 41.5 g. Over the years of testing, the variety was not affected by powdery mildew and brown rust. The variety is characterized by high agroecological adaptability. The average yield for 2015-2017 amounted to 52.6 c/ha, which is 6.0 c/ha higher than the standard of the Krokha variety. Resistance to seed germination on the root is high. It is recommended for production in the Middle Volga region for food and feed purposes.

Another crop of interest to farmers is winter barley. One of the main limiting environmental factors affecting the formation of winter barley grain yield is winter hardiness. Among other crops, winter barley has the lowest resistance to negative factors in winter period. The critical freezing temperature of this culture ranges from -9 to -15 ºС [6, 14]. In the process of selection, scientists were able to increase the resistance of winter barley varieties to the effects of negative temperatures at a depth of the tillering node by 1.5-2.0 ºC.

In some years, in the conditions of the Middle Volga region, the temperature at the depth of the tillering node can drop to critical levels, as a result of which the complete loss of winter barley crops is possible (Figure 2).

The most reliable method for assessing varieties for winter hardiness is to evaluate them in the field conditions on a natural background. Over the years, in the ecological variety testing of the Samara Research Institute of Agriculture, grades of winter barley sent from various scientific research institutions have been evaluated. In 2007, 2008, 2014, overwintering conditions were favorable and...
crops were completely preserved. Overwintering grades ranged from 3.0 to 5.0 scores. In 2010, 2013, the absence of snow cover in December and the low temperature at the depth of the tillering node (minus 12.0-16.4 °C) led to the complete loss of crops. A good differentiation of overwintering varieties was obtained in 2009 and 2015, when the temperature at the depth of the tillering node dropped to minus 7.5-10.7 °C. During these years, most of the varieties of winter barley were completely frozen or severely thinned (0.0-2.5 points), which made it possible to identify valuable source material for use in the breeding process. The best in winter hardiness for all years of study was the Zhiguli variety, which was created jointly by Research Institute of Grain Crops and Samara Research Institute of Agriculture. When studying the Zhiguli variety in the competitive variety testing (2005-2009) of the Samara Research Institute of Agriculture, the grain yield was 36.9 c/ha, which is 2.9 c/ha higher than the standard of Rostov 55 variety (Table 4).

**Table 4.** Characterization of the economic and biological features of the Zhiguli variety in the competitive variety test, Samara Research Institute of Agriculture, 2005-2009.

| Feature                      | Standard of Rostov 55 | Zhiguli  |
|------------------------------|-----------------------|---------|
| Grain harvest, c/ha          | 34.0                  | 36.9    |
| ± to standard grade          | -                     | +2.9    |
| Growing season, days         | 271.0                 | 270.0   |
| Plant height, cm             | 57.3                  | 57.5    |
| Resistance to lodging, score | 9.0                   | 9.0     |
| Number of grains in the ear, pcs | 47.7                | 52.3    |
| Productive bushiness         | 1.3                   | 1.4     |
| Field winter hardiness, score| 4.0                   | 4.0     |
| Weight of 1000 grains, g     | 35.0                  | 36.0    |
| Grain unit, g                | 646.0                 | 642.0   |
| Protein content,%            | 11.9                  | 13.2    |
| Powdery mildew resistance, score | 6.0                 | 8.0     |
| Resistance to net spotting, score | 6.0               | 8.0     |

The number of grains in an ear is 52.3 pcs with a weight of 36.0 g on 1000 grains. The variety is mid-season, the growing period is 270 days, at the standard level. Plant height is 57.5 cm, lodging resistance is high. The variety is characterized by a high protein content in grain of 13.2%. It has a high level of winter hardiness and droughty tolerance. It is resistant to germination of grain on the root. The variety exhibits an average susceptibility to leaf-stem diseases.

In studies of the Samara State Agricultural Academy for 2007-2009 the study of the effect of fertilizers and types of fallows on the passage of the development phases of winter crops by plants showed that they had practically no effect on the duration of interphase periods. Field germination was directly dependent on moisture in the arable soil layer and was determined by the amount of precipitation that fell during the period from harvesting the predecessor to sowing winter crops. On average, over the years of research, field germination in winter wheat and triticale was close and amounted to 88.4...88.8% in the control sample. When fertilizer was applied, it decreased to 83.3...83.9%. This is due to the fact that the productivity of the cropped fallow crop was higher on fertilized backgrounds and less productive moisture remained in the soil. After green-manured fallow, the number of seedlings turned out to be less (80.1...85.2%) as a result of the fact that the moisture loss was greater due to the intensive evaporation of its crushed green manure, embedded in the upper soil layer, and the active propagation of soil microorganisms that use water to life activity. The field germination rate of winter barley compared to winter wheat and triticale was less and amounted to 81.8...84.5% after cropped fallow, 78.9...81.9% after green-manured fallow.

The overwintering of winter wheat after cropped fallow amounted to 78.6...82.6%, after green-manured fallow - 81.1...83.9%; in triticale, the indicators were higher, respectively, 83.0...86.0% and 87.3...91.0%. Winter barley turned out to have the lowest overwintering: after cropped fallow - 77.6...80.3%, after green-manured fallow it was higher - 81.0...82.4%. Due to the action of mineral fertilizers, overwintering increased insignificantly. As a result, the number of winter barley plants
before harvesting after steam cropped fallow in all cases was minimal compared to winter wheat and triticale (291...331 pcs per 1 m²), but higher than after green-manured fallow, where this indicator was 284...324 pcs per 1 m². In triticale and winter wheat, the number of plants before harvesting did not differ significantly, due to its good germination and overwintering compared to winter barley. However, winter barley had higher indicators of productive bushiness compared to other winter crops, due to its biological characteristics. With the introduction of estimated doses of mineral fertilizers, the productive bushiness of winter crops increased compared with the control sample. After the cropped fallow, the number of productive stems was higher compared to green-manured fallow, since the conditions of soil moistening after harvesting the cropped fallow crop during the winter growing season, when the main tillering takes place, were more favorable.

The number of grains in the ear and the mass of 1000 grains of winter barley increased from the action of the calculated doses of mineral fertilizers, and had higher indicators compared to triticale and winter wheat. In winter wheat, the grain was larger compared to triticale, but the number of grains in the ear was less. After green-manured fallow, in all winter crops, these indicators were higher than after the cropped fallow.

In the conditions of the Middle Volga region, which are characterized by insufficient moisture conditions, one of the important factors for obtaining high grain yields is the economical use of soil moisture by plants during the growing season. On average, over the years of research, a higher water consumption per 1 ton of dry matter was 252 m³ in winter wheat in the control sample without fertilizing. With an improvement in the mineral nutrition conditions, water consumption per 1 ton of dry matter decreased to 231 m³ on background 1 and 213 m³ on background 2. The lowest water consumption per 1 ton of dry matter, which amounted to 212 m³ in the control variant, was observed in winter barley plants. When the calculated doses of mineral fertilizers were applied to the grain yield of 2.8 and 3.3 t/ha, the moisture consumption decreased, respectively, to 190 m³ and 180 m³. In plants of winter triticale, the water consumption per 1 ton of dry matter in the control sample was 221 m³, on background 1 - 192 m³ and on background 2 - 182 m³, that is, there were indicators closer to winter barley plants.

On average, over the years of research, the minimum yield in the experiments was formed by winter wheat in the variant without fertilizing after the cropped fallow - 1.76 t/ha (Table 5).

| Experience options | Control sample | Background 1 | Background 2 |
|--------------------|----------------|--------------|--------------|
|                    | cropped fallow | green-manured fallow | cropped fallow | green-manured fallow | cropped fallow | green-manured fallow |
| Winter wheat       | 1.76           | 1.92         | 2.79         | 2.88         | 3.84           | 3.92         |
| Winter triticale   | 2.44           | 2.55         | 2.91         | 3.25         | 4.50           | 4.71         |
| Winter barley      | 2.03           | 2.15         | 3.28         | 3.30         | 4.73           | 4.80         |
| Least significant difference 05 total | 0.15 | 0.17 | 0.14 | 0.17 | 0.16 | 0.11 |

In control sample, higher yield was provided by winter triticale (2.44...2.55 t/ha). When applying the calculated doses of mineral fertilizers, the grain yield of winter wheat increased 1.6...2.2 times, winter triticale 1.2...1.8 times, winter barley 1.6...2.5 times. After green-manured fallow, the yield of winter crops was higher by 0.6...11.2% compared to cropped fallow. Among the studied crops, winter barley was distinguished by a higher yield when applying mineral fertilizers (3.28...4.80 t/ha).

4. Conclusion
In the course of scientific research, it was found that:
- the optimal ratio of wheat flour and triticale flour for baking bread is a ratio of 50: 50;
- the created set of varieties of winter triticale (Krokha, Kapella, Spica, Arktur) fully meets the needs of producers;
- the main factor influencing the overwintering of winter barley in the Middle Volga region is the low temperature at the depth of the tillering node;
- the variety Zhiguli of winter barley to the greatest extent, compared with other varieties, adapted to the climatic conditions of the Middle Volga region;
- when applying mineral fertilizers, winter barley formed a higher yield compared to winter wheat and triticale.

Thus, the introduction of new high-yielding varieties resistant to abiotic and biotic environmental factors for the specified purpose will expand the possibility of using winter triticale and winter barley grains in the agricultural sector, thereby expanding the diversification of winter crops in the Middle Volga region.

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