СЕЛЕКЦИЯ, СЕМЕНОВОДСТВО И БИОТЕХНОЛОГИЯ РАСТЕНИЙ / PLANT BREEDING, SEED PRODUCTION AND BIOTECHNOLOGY

DOI: https://doi.org/10.23649/JAE.2023.40.13

THE BIOCHEMICAL CONTENT OF WINTER TRITICALE VARIETIES IN THE VOLGA REGION OF RUSSIA

Research article

Ponomareva M.L.[1,] *, Ponomarev S.N.[2], Mannapova G.S.[3]
[1] ORCID : 0000-0002-1648-3938;
[2] ORCID : 0000-0001-8898-4435;
[3] ORCID : 0000-0002-9097-783X;
[1, 2, 3] Tatar Scientific Research Institute of Agriculture FRC “KazSC RAS”, Kazan, Russian Federation

* Corresponding author (smponomarev[at]yandex.ru)

Abstract

The results of the evaluation of the biochemical composition and feed value of 5 winter triticale varieties (Nemchinovsky 56, Cornet, Bashkirskaya short-stem, Beta, Svetlitsa) are presented. The research was carried out in the Tatarstan Republic during 10 years of different hydrothermal regime (2011-2020). Characterization of biochemical composition of forage is necessary for calculation of nutritive value of feed, both in feed units and in energy units. The influence of genotype on parameters such as crude protein, fibre, fat, sugar, calcium, and phosphorus content has been statistically demonstrated. Svetlitsa was the best variety for crude protein and sugar content, Cornet for fibre, Nemchinovsky 56 for fat, Beta for phosphorus and Bashkirsky short-stem for calcium. The development of all biochemical parameters of triticale grain was significantly influenced by environmental factors. The highest coefficient of variation between varieties was observed for protein and fibre content. In terms of metabolizable energy content, the evaluated triticale varieties correspond to class 1 for cattle and sheep, and class 2 for pigs and poultry of the Russian standard used for forage triticale.

Using the method of Principal Component Analysis, three leading factors of variation of the studied indicators of nutritive and energy value of triticale, named "utilization and availability", "feed nutrition", "phosphorus supply", were determined. The identified components can be used for planning the selection process of winter triticale for feed purposes.

Keywords: triticale, variety, fodder quality, energy value, biochemical composition, principal component analysis.

БИОХИМИЧЕСКИЙ СОСТАВ СОРТОВ ОЗИМОЙ ТРИТИКАЛЕ В ПОВОЛЖСКОМ РЕГИОНЕ РОССИИ

Научная статья

Пономарева М.Л.[1,] *, Пономарев С.Н.[2], Маннапова Г.С.[3]
[1] ORCID : 0000-0002-1648-3938;
[2] ORCID : 0000-0001-8898-4435;
[3] ORCID : 0000-0002-9097-783X;
[1, 2, 3] Татарский научно-исследовательский институт сельского хозяйства ФИЦ КазНЦ РАН, Казань, Российская Федерация

* Корреспондирующий автор (smponomarev[at]yandex.ru)

Аннотация

Представлены результаты оценки биохимического состава и кормовой ценности 5 сортов озимой тритикале (Немчиновский 56, Корнет, Башкирская короткостебельная, Бета, Светлица). Исследования проводились в Республике Татарстан в течение 10 лет, различающихся по гидротермическому режиму (2011-2020 гг.). Характеристика биохимического состава кормов необходима для расчета питательной ценности корма, как в кормовых единицах, так и в энергетических единицах. Статистически доказано влияние генотипа на такие показатели, как содержание сырого протеина, клетчатки, жира, сахара, кальция и фосфора. По содержанию сырого протеина и сахара лучшим оказался сорт Светлица, по содержанию клетчатки – Корнет, по содержанию жира – Немчиновский 56, по содержанию фосфора – Бета, по содержанию кальция – Башкирская короткостебельная. На развитие всех биохимических показателей зерна тритикале существенное влияние оказывали факторы внешней среды. Наибольший межсортовой коэффициент вариации наблюдался по содержанию белка и клетчатки. По содержанию обменной энергии оцениваемые сорта тритикале соответствуют 1 классу для крупного рогатого скота и овец и 2 классу для свиней и птицы российского стандарта, используемого для кормовой тритикале.

С помощью метода анализа главных компонент были определены три ведущих фактора варьирования изучаемых показателей питательной и энергетической ценности тритикале, названные «использование и доступность», «питательность корма», «обеспеченность фосфором». Выявленные компоненты могут быть использованы для планирования селекционного процесса озимой тритикале на кормовые цели.

Ключевые слова: тритикале, сорт, кормовые качества, энергетическая ценность, биохимический состав, анализ главных компонент.

Introduction

Triticale (x Triticosecale Wittmack), a cereal synthesized from the wheat and rye genomes, is a versatile raw material for a range of products. This makes it an attractive option for farmers looking to maximize their output [16, P. 407], [20, P. 16]. It combines the yield potential and grain quality of wheat with the disease and environmental tolerance of rye, making it a promising food crop. Triticale boasts significantly higher yield potential on poor soils where wheat does not produce high-quality grain, while also offering lower production costs [8, P. 26], [12, P. 823], [22, P. 17].

Triticale has grown in economic importance, particularly in Europe, in recent years. With 1.3 million hectares of triticale, Poland contributes to a third of the world's production and remains the top producer of this crop [5]. In 2022, the Russian Federation will produce 270,000 tonnes of triticale grain and the area under this crop will be 96,000 ha. The Belgorod, Rostov, Volgograd, Novosibirsk, and Bryansk regions had the most extensive triticale cultivation areas.

Modern triticale varieties have diverse uses across the food industry, animal feed production, and bio-industrial processing sectors. The grain's composition is favourable for both technological and nutritional purposes, making it an ideal resource for producing flour and bread [6, P. 67]. Due to the growing concern for the environment, triticale production has garnered interest as an energy crop and industrial biofuel [24, P. 47].

Nutrients of triticale that are currently attracting research attention include starch, non-starch polysaccharides (such as arabinoxylans), polyphenols (such as phenolic acids), alkylresorcinols, and vitamins (such as vitamin B1) [21, P. 325]. However, the most crucial direction is to incorporate triticale grains into animal feed instead of relying on wheat and barley [3, P. 20].

Triticale is a food rich in carbohydrates and energy. It contains 3.4% less metabolic energy than wheat, but exceeds it in crude protein (15.1% vs. 11.5%) and essential amino acids. The crude fibre content of triticale grain is 0.2% lower than that of wheat [18, P. 370]. Studies confirm the efficiency of using triticale grain to fatten pigs [4, P. 5698], [25, P. 1614], rear young cattle [17, P.126], and raise poultry [11, P. 2], [26, P. 75]. Proposals have been put forward to enlarge the proportion of triticale grain in the diet of non-ruminants. The grain of this cereal has been identified by most researchers as a factor that enhances animal productivity while also reducing feed expenses.

In recent times, triticale's chemical composition range has grown due to more genetic resources being inspected [14, P. 541].

Currently, triticale is used as a substitute for other cereals, particularly wheat, in animal feed [2, P.1130], [15, P. 1156]. Its chemical composition is more similar to that of wheat than to that of rye, and most of the nutritional compounds are slightly greater than in wheat [7, P. 74]. One notable feature of triticale is its high protein content, with a better balance of amino acids than wheat [1, P. 278]. These attributes are beneficial for the pig [4, P. 5701] and poultry sectors [7, P. 88] and are frequently utilized as forage or feed for ruminants, in the form of silage or hay [8, P. 156]. Pentosans, including some β-glucans, are the major non-starch polysaccharide (NSP) constituents in the endosperm cell walls of triticale [18, P. 372], which is similar to wheat and rye. There is significant variation in the chemical composition, nutritional content and feed value of triticale grain depending on the genetic characteristics of the cultivars, as stated in [17, P. 127]. The production rate of the crop is limited due to the lack of information on the benefits and variability of new forage triticale cultivars.

The aim of our research is to evaluate the chemical composition and feed value of different winter triticale cultivars grown in the Volga region of Russia.

Research methods and principles

Field trials were carried out from 2011-2020 at the Tatar Scientific Research Institute of Agriculture at the Kazan Scientific Centre of the Russian Academy of Sciences in the Republic of Tatarstan. The study focused on five winter triticale cultivars (Nemchinovsky 56, Cornet, Bashkir short-stem, Beta and Svetlitsa) bred in Russia from different ecological origins. Weather conditions varied during the spring and summer growth period for triticale crops (from April to July) over the course of the experiments. In 2011, 2013, and 2014, precipitation was below the annual average of 190 mm, whereas in 2015 it significantly exceeded this value at 224 mm. The average temperature during this time was higher than usual. The spring and summer months of 2017 and 2020 experienced moderate levels of precipitation, while 2018 and 2019 suffered from drought.

The grey forest soil of the research field had a 3.1% organic matter and pH of 6.2. The cereals had low levels of available nitrogen (112.0 mg/kg), high levels of available phosphorus (342 mg/kg) and low levels of available potassium (56.5 mg/kg).

Chemical composition analyses were conducted in each season through commonly accepted methods. The study investigated various characteristics, including dry matter content (DM), crude protein content (Pro), crude fibre content (Fi), crude fat content (Fa), ash content (A), feed value (FV), metabolizable energy (ME), free nitrogen extractable matter (FNEM), sugar content (SC), calcium (Ca), and phosphorus (P). The feed units (FU) and metabolizable energy (ME) were calculated according to Kalashnikov et al. [10, P. 75].

The data were analysed using Fisher's two-way analysis of variance (ANOVA). Then, the experimental data was processed using Principal Component Analysis (PCA) with Varimax rotation and clustering methods of Agglomerative Hierarchical Clustering, using the XLSTAT package (version 2019.3).

Main results

Two-way analysis of variance revealed significant differences ($P < 0.01$) between genotypes for Pro, Fi, Fa, SC, Ca, and P (Table 1). Environmental effects and "genotype x environment" interaction effects were observed for all tested parameters except DM. All triticale genotypes were highly influenced by the genotypes, for example Pro, Fi, Fa, Ca, P and SC (Table 1). The variability of the "environment" factor, determined by the mean square, significantly exceeds the variation of the "genotype" factor for most of the traits, indicating the predominance of environmental effects in the phenotypic variability of the triticale forage advantages. Thus, the meteorological conditions of the growing season have a greater effect on the variability than the genetic factor, judging by the size of the variance.

Table 1 - Analysis of variance for the characteristics of the grain chemical composition of the winter triticale varieties

DOI: https://doi.org/10.23649/JAE.2023.40.13.1

	Mean squares

DM	0,158	3,661**	0,126	0,104
Pro	5,273**	45,662**	1,938*	0,825
Fi	1,889**	6,254**	0,774**	0,137
Fa	0,109**	0,883**	0,141**	0,021
A	0,016	0,700**	0,034**	0,012
Ca	0,00085**	0,00694**	0,00080**	0,00014
P	0,00144**	0,01577**	0,00176**	0,00032
SC	7,158**	27,780**	1,645**	0,567

*Note: * 5 % level of significance, ** 1% level of significance*

The mean values for the chemical composition and feed value of triticale are shown in Table 2. The mean values of DM and FNEM varied within narrow intervals 92.95%...93.22% and 73.52%...74.41%, respectively, without exceeding random deviations.

Table 2 - Chemical compositio and feed value of the grain of winter triticale varieties in the air-dried state

DOI: https://doi.org/10.23649/JAE.2023.40.13.2

Trait	Nemchinovsky 56	Cornet	Bashkir short-stem	Beta	Svetlitsa
DM, %	93,19	93,17	92,95	93,03	93,22
Pro, %	14,44	13,86	14,06	14,84	15,52
Fi, %	3,21	3,27	3,06	2,98	2,28
Fa, %	1,54	1,44	1,28	1,48	1,46
A, %	1,85	1,82	1,76	1,79	1,83
Ca, %	0,12	0,12	0,14	0,12	0,13
Ph, %	0,22	0,24	0,23	0,25	0,23
SC, %	4,67	4,80	4,45	5,82	6,20
FNEM, %	73,81	74,21	74,41	73,6	73,52
Feed units	1,244	1,241	1,251	1,244	1,245
ME, MJ/kg	13,87	13,80	13,83	13,87	13,88

The big problem is the limited availability and high cost of protein feed. Therefore, protein content is the main criterion for evaluating triticale grain. The protein content ranged from 13.86% (Cornet) to 15.52% (Svetlitsa). ANOVA showed that the studied genotypes differed significantly from each other on this basis. Cultivar Svetlitsa significantly outperformed all cultivars studied, except Beta.

Further studies (2017-2020) showed that in the variety Bashkir short-stem the protein content varied from 12.9 to 15.4%, the average value of the trait for 4 years was 14% (Fig. 1). Triticale Nemchinovsky 56 had a variation amplitude of 12.7...15.3% and the average value of the characteristic was 13.5%. The best performer was the variety Svetlitsa, whose protein content varied in the same years from 14.1 to 16.7%, with an average value of 15.2%. The coefficient of variation of Pro was 25.3%, which indicates its significant variability depending on the emerging climatic factors.

Crude fibre content occupies a special place among the nutrients and determines the degree of digestibility of the forage. The analysis of Fi content showed a range from 2.28 to 3.27% (Table 2), and the intervarietal coefficient of variation, which shows the variability of Fi among years and varieties, was significant – 32.7%. Fi was significantly lower in variety Svetlitsa (2.28%) than in all the others.

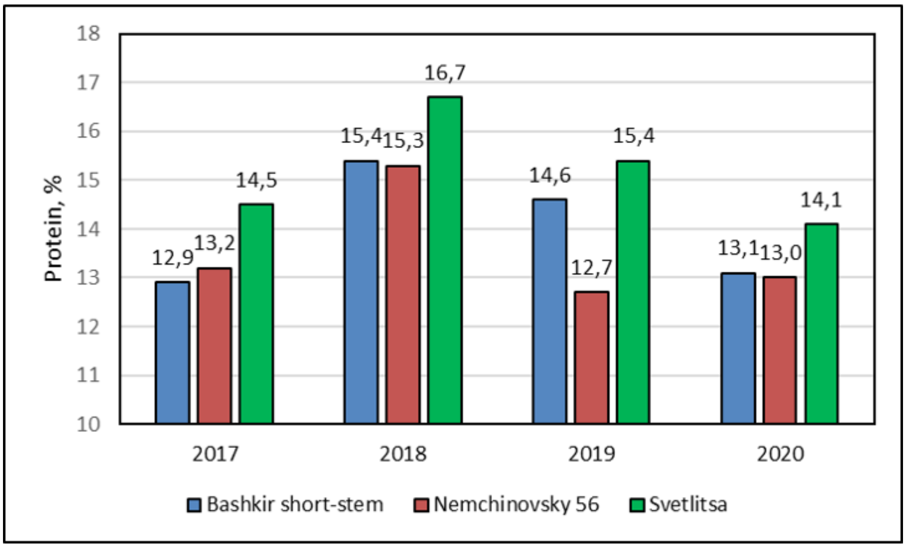

Figure 1 - Protein content of winter triticale varieties
DOI: https://doi.org/10.23649/JAE.2023.40.13.3

The next important parameter used to calculate the feed value of grain is the crude fat content. Four out of the five cultivars represented were in the same group with the value of this indicator at the level of 1.44...1.54 %. The exception was the cultivar Bashkir short-stem, which was characterized by a lower fat content (1.28 %).

Statistically confirmed differences in the amounts of sugar, phosphorus and calcium were observed between the investigated varieties of winter triticale. Calcium content in the studied triticale varieties varied from 0.12 to 0.14%, the highest being in Bashkir short-stem. Phosphorus content ranged from 0.22 to 0.25%, the highest being in Beta. The value of SC showed significant advantages in the varieties Beta and Svetlitsa (see Table 2).

Feed contains ingredients that the animal can use as fuel. But even fuel is not energy. This depends on the metabolically active components in the feed, such as sugars, fibre, fat and protein. The evaluation of the nutritional value of grain feed from triticale in oat feed units did not show any difference between the analyzed varieties (1,241...1,251 f.u.). It is believed that the assessment of the nutritional value of diets using metabolic energy indicators is more accurate because it takes into account all the physiologically beneficial effects of the feed on the animal's body, and not just the productive effects. In our studies, despite the differences in biochemical composition, the generalized indicators of energy value were quite similar and ranged from 13.80 MJ in cultivar Cornet to 13.88 MJ in Svetlitsa.

Therefore, we applied the method of principal components, highlighting the correlated and interdependent indicators. In order to reduce the number of average correlations and bind each variable to only one component, varimax rotation, an important step in the PCA analysis, was used.

Based on the analysis of the calculated correlation matrix, the contributions with which the characteristics are included in the principal components (PC), i.e. new quality characteristics, are obtained. They reflect different reasons for the variability of the quality characteristics, and their importance is estimated by the share of the variance in the total variance of the characteristic. Moreover, the first three selected components, for which the variance >1, accounted for 93.28% of the total variability (Fig. 2). Therefore, further analysis was carried out using only these components.

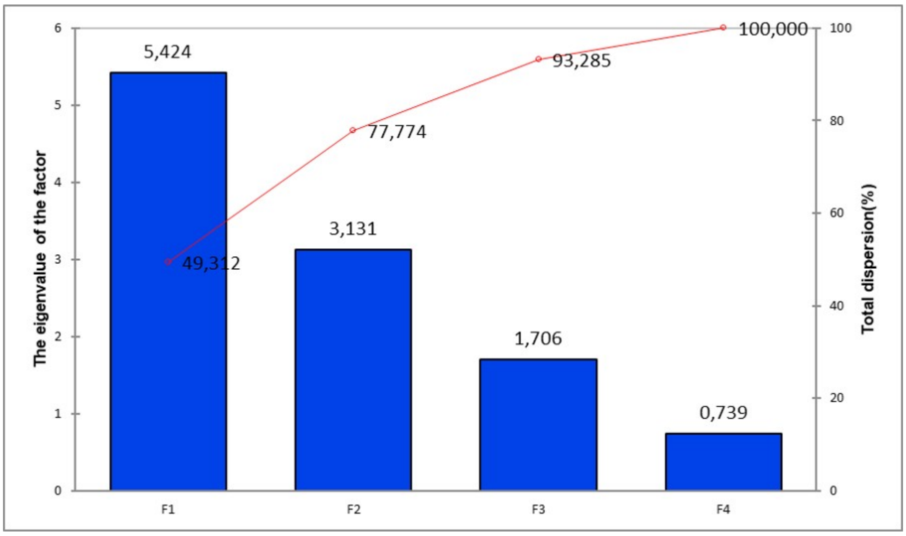

Figure 2 - Fraction of variability attributable to principal components
DOI: https://doi.org/10.23649/JAE.2023.40.13.4

Note: F1-F4

Verification of factor loads showed that a number of variables have low weight values, as a result of which their ordering was required. For this, it was necessary to form the main components in such a way that the studied parameters had a factor weight for this component of at least 0.7. The task was to select the axes in such a way as to give the new variables a specific meaning. For this purpose, the element of their rotations was used with the Varimax raw procedure, which leads to an increase in large and a decrease in small values of factor loads.

After rotation, the first component explained 39.18 % of the total variance, the second – 38.33%, the third – 15.76% (Table 3). The both first and second main components were most correlated with all the initial features, determining the largest part of their variability. The third principal component described the third-largest fraction of variability, and was characterized by zero correlation with the first two. Structure listed main components with varimax-rotation was unchanged.

The principal components' method allows not only a more logical explanation of the resulting data matrix, but also the visualization of the results of its analysis. Therefore, the available results of the correlation of the study objects (varieties and their zootechnical characteristics) were presented in the form of a dispersion graph on the axes of the principal components D1-D2 (Fig. 3).

According to the graph, the subset of characteristics "metabolic energy, total sugars and protein" correspond to the varieties Svetlitsa and Beta. In addition, these varieties had similar ash, fat, and dry matter contents in the grain.

Table 3 - Matrix of factor loads of the characteristics of chemical composition and nutritional value of winter triticale grains

DOI: https://doi.org/10.23649/JAE.2023.40.13.5

Rate	Main component		
	1	2	3
DM, %	0,268	0,767	0,441

Pro, %	0,995	0,081	0,063
Fi, %	-0,903	0,191	-0,132
Fa, %	0,310	0,910	0,091
A, %	0,187	0,840	0,502
Ca, %	0,060	-0,944	0,265
P, %	0,061	0,054	-0,993
SC, %	0,912	0,184	-0,316
FNEM, %	-0,862	-0,467	0,064
Feed units	0,029	0,946	0,231
ME, MJ	0,849	0,106	0,211
Dispersion, %	39,185	38,332	15,768
Cumulative dispersion, %	39,185	77,517	93,285

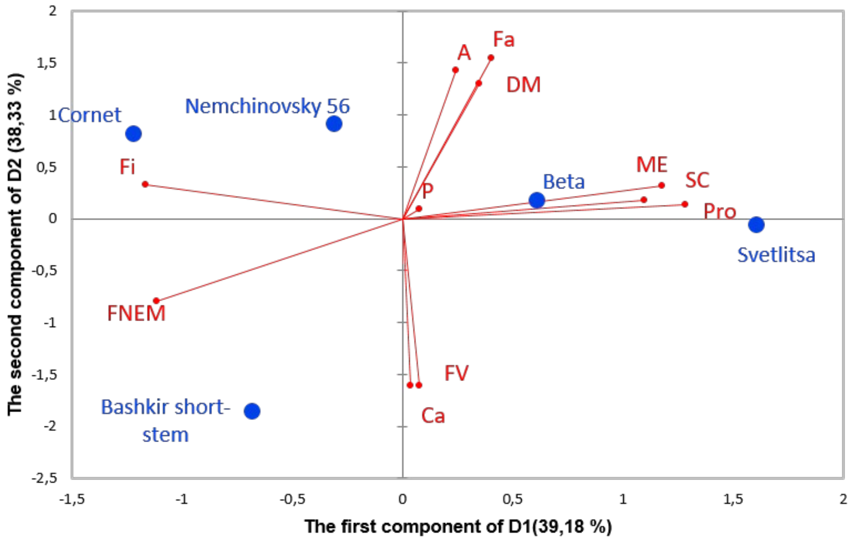

Figure 3 - The location of varieties and indicators in the space of the first principal components after varimax rotation in accordance with their load

DOI: https://doi.org/10.23649/JAE.2023.40.13.6

Note: D1, D2; the lines show the eigenvectors of the leading factor loads

Discussion

In this work we have carried out a study of the chemical composition and nutritional value of five varieties of winter triticale, two of which (Beta and Svetlitsa) are varieties of our own selection. We found a significant environmental influence and genotype x environment interaction effects for all the parameters investigated characterizing the feed value of triticale grain, except for dry matter content. The greatest influence of genotype was found for the protein content, fibre content, fat content, sugar content, calcium, and phosphorus.

In the literature, information on Pro in triticale grain varies widely – from 11 to 20% [13, P. 584], [18, P. 370], [27, P. 468]. Such large variations may reflect the influence of climatic conditions [16, P. 430]. Moreover, the protein profile of winter triticale is genetically determined [9, P. 29]. At the same time, triticale can produce more feed protein per hectare than other cereals because winter varieties have a higher protein content in the grain and higher yields [23, P. 10].

Our study indicated that the mean protein content of various triticale cultivars ranged from 13.86-15.52% (refer to Table 2). Nonetheless, it was observed that there can be substantial variation in this trait between years within the same cultivar due to weather conditions (see Fig. 1). The difference in Pro values within the same year was 2.5-2.6%. The cultivar Svetlitsa contained the highest protein content in the grain, with levels reaching 16.7% in some years (2018).

Alijošius et al. [1, P. 276] found low coefficients of variation in crude protein and starch content, medium – in fat and ash, medium and high in different years – in crude fibre content. Swedish scientists Pettersson and Aman [19, P. 21] showed that modern high-yielding Swedish, Polish and Russian varieties, and old lines of winter triticale had very significant coefficients of variation for protein content in triticale grain (CV = 25.3%). In addition, the same authors demonstrated the influence of genetic and environmental factors on fat content and found that the examined varieties had a mean fat content of 2.2% with a variation of 1.0 to 2.9% and a coefficient of variation of 17.5% [19, P. 25]. Our studies also showed high coefficients of variation for protein (25.3%) and fibre content (32.7%) in triticale grain.

Based on the standardized indicators for feed triticale quality and nutritional value (GOST R 53899-2010), the metabolic energy content of the examined triticale varieties is classified as first class for cattle and sheep (greater than 13.0 MJ/kg) and second class for pigs and poultry (13.0...14.0 MJ/kg).

We assessed the nutritional value of the diets by evaluating the chemical composition, nutrient digestibility and energy content of the triticale grain using principal component analysis.

The first component of triticale forage can be described as "utilisation and availability". It is characterised by the most significant influences of P, SC, ME and negative factors in Fi and FNEM. This means that these characteristics change consistently and respond in the same way to variations in environmental conditions, regardless of the variety. However, the factor loadings' signs are not alike. In order to achieve high nutrient digestibility in triticale, it is essential to achieve an optimum balance in the biochemical composition of the grain and to use successful breeding techniques. Any deviation from the optimal equilibrium of these nutrients is consequential, leading to a reduction in digestibility, which in turn diminishes the feed's energy content [25, P. 1625]. SC and Pro have the most significant impact on metabolism. The inclusion of high fibre triticale grain results in decreased nutrient digestibility. The inclusion of non-starch polysaccharides like pentosans, pectin, and glucans in cereals significantly impacts the digestibility of nitrogen-free extractives. In terms of zootechnical value for animals, the amount of carbohydrates in triticale grain (SC and FNEM) affects the rate of feed element decomposition for energy production.

The second major component, as shown in Table 3, is closely linked to dry matter, fat, ash, feed units, and calcium content (with a negative value). This could be seen as indicative of its nutritional value. The feed intake level in triticale is influenced by several factors [7, P. 88]. Among these factors, the most important are the dry matter and crude fat content, which act as a source of energy and heat in the body. Crude ash is also involved in almost all significant processes of animal activity [21, P. 326], including metabolic processes and mineral and water balance.

The third component boasts the highest phosphorus content, which is a comparatively expensive component in animal feed formulations. Our research has demonstrated significant variability in the value of this indicator between cultivars, however, its variation under the influence of external factors appears to be the most substantial. We posit that a critical factor in the accumulation of this element in the crop is the high phosphorus content present in the experimental plot's soil.

Conclusion

The use of triticale grain for feed purposes is a very important area necessary for the nutrition of cattle, pigs, and poultry. We have shown a significant influence of varietal characteristics (genetic factor) on the biochemical composition of the grain and, consequently, on its feed value. The influence of genotype on indicators such as crude protein, fibre, fat, sugar, calcium, and phosphorus content has been statistically proven. According to these indicators, it is possible to further improve them using available breeding methods. The varieties studied differed significantly in their biochemical composition. The Svetlitsa cultivar was the best for crude protein and sum of total sugars, the Cornet cultivar was the best for fibre and the Nemchinovsky 56 cultivar was the best for fat. Beta was the best for phosphorus and Bashkirsky short stem was the best for calcium. Further breeding work with winter triticale should be carried out with a view to increasing the feed value of the grain.

The development of nutritive value of triticale grain was significantly influenced by environmental factors. The highest coefficient of variation between varieties was observed for protein and fibre content indicators.

Despite significant differences in the biochemical composition of the grain, the varieties were similar in terms of metabolizable energy and feed units. In terms of metabolizable energy content, the triticale varieties studied correspond to the 1st class for cattle and sheep and to the 2nd class for pigs and poultry.

The method of Principal Component Analysis made it possible to transform the totality of the biochemical characteristics studied into new indices - a system of three principal components ordered according to the variance explained by them. The leading factors of variation of the studied indicators of nutritional and energy value of triticale, named "utilisation and availability", "feed nutrition", "phosphorus supply", were identified. The identified components can be used for planning the selection process of winter triticale for feeding purposes.

Финансирование

Исследование выполнено в рамках Государственного задания ФИЦ КазНЦ РАН, №1220118000138-7.

Конфликт интересов

Не указан.

Рецензия

Все статьи проходят рецензирование. Но рецензент или автор статьи предпочли не публиковать рецензию к этой статье в открытом доступе. Рецензия может быть предоставлена компетентным органам по запросу.

Funding

The research was carried out within the State assignment of FRC “KazSC RAS”, №1220118000138-7.

Conflict of Interest

None declared.

Review

All articles are peer-reviewed. But the reviewer or the author of the article chose not to publish a review of this article in the public domain. The review can be provided to the competent authorities upon request.

Список литературы / References

1. Alijošius S. Grain Chemical Composition of Different Varieties of Winter Cereals / S. Alijošius, G.J. Švirmickas, S. Bliznikas // Zemdirbyste-Agriculture. — 2016. — 3. — p. 273-280. — DOI: 10.13080/z-a.2016.103.035.

2. Ayalew H. Triticale Improvement for Forage and Cover Crop Uses in the Southern Great Plains of the United States / H. Ayalew, T. T. Kumssa, T. J. Butler // Frontiers in Plant Science. — 2018. — 1. — DOI: 10.3389/fpls.2018.01130.

3. Biel W. Nutritional Value of Wheat, Triticale, Barley and Oat Grains / W. Biel, K. Kazimierska, U. Bashutska // Acta Scientiarum Polonorum Zootechnica. — 2020. — 2. — DOI: 10.21005/asp.2020.19.2.03.

4. Djekic V. Implementation of Triticale in Nutrition of Non-ruminant Animals / V. Djekic, S. Mitrovic, M. Milovanovi // African Journal of Biotechnology. — 2011. — 30. — DOI: 10.5897/AJB10.986.

5. Statistics Division of Food and Agriculture Organization of the United Nations. — 2023 — URL: https://www.fao.org/faostat/en/#data/QCL (accessed: 12.11.2023)

6. Fraś A. Variability in the Chemical Composition of Triticale Grain, Flour and Bread / A. Fraś, K. Gołębiewska, D. Gołębiewski // Journal of Cereal Science. — 2016. — 1. — DOI: 10.1016/j.jcs.2016.06.016.

7. Glamočlija N. The Importance of Triticale in Animal Nutrition / N. Glamočlija, M. Starčević, J. Ćirić // Veterinary Journal of Republic of Srpska. — 2018. — 1.

8. Grabovets A.I. Тритикале / A.I. Grabovets, A. V. Krochmal // Юг. — 2018. — 1.

9. Jaśkiewicz B. Amino Acids Content in Triticale Grain Depending on Meteorological, Agrotechnical and Genetic Factors / B. Jaśkiewicz, M. Szczepanek // Research for Rural Development. — 2018. — 5. — DOI: 10.22616/rrd.24.2018.047.

10. Kalashnikov A. P. Feeding Norms and Diets for Farm Animals / A. P. Kalashnikov, V. I. Fisinin, V. V. Shcheglov // Moscow: Agropromizdat. — 2003. — 1.

11. Kliseviciute V. Effect of Different Supplementation Levels of Whole Triticale Grown in Lithuania to Broiler Diets on Performance and Parameters of Functioning of the Digestive Tract / V. Kliseviciute, R. Gruzauskas, M. A. Grashor // European Poultry Science. — 2014. — 1. DOI: 10.1399/eps.2014.34.

12. Kwiatek M. T. Chromosome Manipulations for Progress of Triticale (× Triticosecale) Breeding / M. T. Kwiatek, J. Nawracała // Plant Breeding. — 2018. — 6. — DOI: 10.1111/ pbr.12652.

13. Leeson S. Response of White Leghorns to Diets Containing Ground or Whole Triticale / S. Leeson, J. D. Summers // Canadian Journal of Animal Science. — 1987. — 2. — DOI: 10.4141/cjas87-060.

14. Manley M. Prediction of Triticale Grain Quality Properties, Based on Both Chemical and Indirectly Measured Reference Methods, Using Near-Infrared Spectroscopy / M. Manley, C. M. McGoverin, F. Snyders // Cereal Chemistry. — 2013. — 6. — DOI: 10.1094/CCHEM-02-13-0021-R.

15. McGoverin C. M. A Review of Triticale Uses and the Effect of Growth Environment on Grain Quality / C. M. McGoverin, F. Snyders, N. Muller // Journal of the Science of Food and Agriculture. — 2011. — 7. — DOI: 10.1002/jsfa.4338.

16. Mergoum M. Triticale (x Triticosecale Wittmack) Breeding / M. Mergoum, S. Sapkota, A. E. A. El Doliefy // Advances in Plant Breeding Strategies: Cereals. — 2019. — 1. — DOI: 10.1007/978-3-030-23108-8.

17. Milovanovic M. Possibilities for Growing of Some Facultative Triticale Cultivars / M. Milovanovic, V. Pericic, M. Stalevic // Contemporary Agriculture. — 2005. — 1(2).

18. Moharrery A. Performance Characteristics and Nutritional Comparison of Broiler Chickens Fed with Barley and Triticale Based Diets / A. Moharrery, E. Asadi, R. Rezaei // Iranian Journal of Applied Animal Science. — 2015. — 2.

19. Pettersson D. The Variation in Chemical Composition of Triticales Grown in Sweden / D. Pettersson, P. Aman // Acta Agriculturae Scandinavica. — 1987. — 1. — DOI: 10.1080/00015128709436540.

20. Potapova G.N. Studying and Breeding Winter Triticale for Feed Quality of Grain / G.N. Potapova, N.N. Zezin, N.L. Zobnina // Feed Production. — 2016. — 3.

21. Rakha A. Dietary Fiber in Triticale Grain: Variation in Content, Composition, and Molecular Weight Distribution of Extractable Components / A. Rakha, P. Åman, R. Andersson // Journal of Cereal Science. — 2011. — 3. — DOI: 10.1016/j.jcs.2011.06.010.

22. Randhawa H.S. Triticale Breeding – Progress and Prospect / H.S. Randhawa, L. Bona, R.J. Graf. — Cham: Springer, 2015. — 17 p. — DOI: 10.1007/978-3-319-22551-7_2.

23. Różewicz M. Yield, Grain Quality and Potential Use of Triticale in Poland / M. Różewicz // Polish Journal of Agronomy. — 2022. — 49. — DOI: 10.26114/pja.iung.487.2022.49.02.

24. Sanaei S. Systematic Assessment of Triticale-based Biorefinery Strategies: Techno-economic Analysis to Identify Investment Opportunities / S. Sanaei, P. R. Stuart // Biofuels, Bioproducts and Biorefining. — 2018. — 1. — DOI: 10.1002/bbb.1499.

25. Strang E. J. P. Variations in the Chemical Composition and Standardized Ileal Digestibility of Amino Acids in Eight Genotypes of Triticale Fed to Growing Pigs / E.J.P. Strang, M. Eklund, P. Rosenfelder // Journal of Animal Science. — 2017. — 4. — DOI: 10.2527/jas.2016.1238.

26. Widodo A.E. The Nutritional Value of New Varieties of High-yielding Triticale: Feeding Value of Triticale for Broiler Chickens / A.E. Widodo, J.V. Nolan, P.A. Iji // South African Journal of Animal Science. — 2015. — 1. — DOI: 10.4314/sajas.v45i1.9.

27. Zhu F. Triticale: Nutritional Composition and Food Uses / F. Zhu // Food Chemistry. — 2018. — 1. — DOI: 10.1016/j.foodchem.2017.09.009.

Список литературы на английском языке / References in English

1. Alijošius S. Grain Chemical Composition of Different Varieties of Winter Cereals / S. Alijošius, G.J. Švirmickas, S. Bliznikas // Zemdirbyste-Agriculture. — 2016. — 3. — p. 273-280. — DOI: 10.13080/z-a.2016.103.035.

2. Ayalew H. Triticale Improvement for Forage and Cover Crop Uses in the Southern Great Plains of the United States / H. Ayalew, T. T. Kumssa, T. J. Butler // Frontiers in Plant Science. — 2018. — 1. — DOI: 10.3389/fpls.2018.01130.

3. Biel W. Nutritional Value of Wheat, Triticale, Barley and Oat Grains / W. Biel, K. Kazimierska, U. Bashutska // Acta Scientiarum Polonorum Zootechnica. — 2020. — 2. — DOI: 10.21005/asp.2020.19.2.03.

4. Djekic V. Implementation of Triticale in Nutrition of Non-ruminant Animals / V. Djekic, S. Mitrovic, M. Milovanovi // African Journal of Biotechnology. — 2011. — 30. — DOI: 10.5897/AJB10.986.

5. Statistics Division of Food and Agriculture Organization of the United Nations. — 2023 — URL: https://www.fao.org/faostat/en/#data/QCL (accessed: 12.11.2023)

6. Fraś A. Variability in the Chemical Composition of Triticale Grain, Flour and Bread / A. Fraś, K. Gołębiewska, D. Gołębiewski // Journal of Cereal Science. — 2016. — 1. — DOI: 10.1016/j.jcs.2016.06.016.

7. Glamočlija N. The Importance of Triticale in Animal Nutrition / N. Glamočlija, M. Starčević, J. Ćirić // Veterinary Journal of Republic of Srpska. — 2018. — 1.

8. Grabovets A.I. Tritikale [Triticale] / A.I. Grabovets, A. V. Krochmal // South. — 2018. — 1. [in Russian]

9. Jaśkiewicz B. Amino Acids Content in Triticale Grain Depending on Meteorological, Agrotechnical and Genetic Factors / B. Jaśkiewicz, M. Szczepanek // Research for Rural Development. — 2018. — 5. — DOI: 10.22616/rrd.24.2018.047.

10. Kalashnikov A. P. Feeding Norms and Diets for Farm Animals / A. P. Kalashnikov, V. I. Fisinin, V. V. Shcheglov // Moscow: Agropromizdat. — 2003. — 1.

11. Kliseviciute V. Effect of Different Supplementation Levels of Whole Triticale Grown in Lithuania to Broiler Diets on Performance and Parameters of Functioning of the Digestive Tract / V. Kliseviciute, R. Gruzauskas, M. A. Grashor // European Poultry Science. — 2014. — 1. DOI: 10.1399/eps.2014.34.

12. Kwiatek M. T. Chromosome Manipulations for Progress of Triticale (× Triticosecale) Breeding / M. T. Kwiatek, J. Nawracała // Plant Breeding. — 2018. — 6. — DOI: 10.1111/ pbr.12652.

13. Leeson S. Response of White Leghorns to Diets Containing Ground or Whole Triticale / S. Leeson, J. D. Summers // Canadian Journal of Animal Science. — 1987. — 2. — DOI: 10.4141/cjas87-060.

14. Manley M. Prediction of Triticale Grain Quality Properties, Based on Both Chemical and Indirectly Measured Reference Methods, Using Near-Infrared Spectroscopy / M. Manley, C. M. McGoverin, F. Snyders // Cereal Chemistry. — 2013. — 6. — DOI: 10.1094/CCHEM-02-13-0021-R.

15. McGoverin C. M. A Review of Triticale Uses and the Effect of Growth Environment on Grain Quality / C. M. McGoverin, F. Snyders, N. Muller // Journal of the Science of Food and Agriculture. — 2011. — 7. — DOI: 10.1002/jsfa.4338.

16. Mergoum M. Triticale (x Triticosecale Wittmack) Breeding / M. Mergoum, S. Sapkota, A. E. A. El Doliefy // Advances in Plant Breeding Strategies: Cereals. — 2019. — 1. — DOI: 10.1007/978-3-030-23108-8.

17. Milovanovic M. Possibilities for Growing of Some Facultative Triticale Cultivars / M. Milovanovic, V. Pericic, M. Stalevic // Contemporary Agriculture. — 2005. — 1(2).

18. Moharrery A. Performance Characteristics and Nutritional Comparison of Broiler Chickens Fed with Barley and Triticale Based Diets / A. Moharrery, E. Asadi, R. Rezaei // Iranian Journal of Applied Animal Science. — 2015. — 2.

19. Pettersson D. The Variation in Chemical Composition of Triticales Grown in Sweden / D. Pettersson, P. Aman // Acta Agriculturae Scandinavica. — 1987. — 1. — DOI: 10.1080/00015128709436540.

20. Potapova G.N. Studying and Breeding Winter Triticale for Feed Quality of Grain / G.N. Potapova, N.N. Zezin, N.L. Zobnina // Feed Production. — 2016. — 3.

21. Rakha A. Dietary Fiber in Triticale Grain: Variation in Content, Composition, and Molecular Weight Distribution of Extractable Components / A. Rakha, P. Åman, R. Andersson // Journal of Cereal Science. — 2011. — 3. — DOI: 10.1016/j.jcs.2011.06.010.

22. Randhawa H.S. Triticale Breeding – Progress and Prospect / H.S. Randhawa, L. Bona, R.J. Graf. — Cham: Springer, 2015. — 17 p. — DOI: 10.1007/978-3-319-22551-7_2.

23. Różewicz M. Yield, Grain Quality and Potential Use of Triticale in Poland / M. Różewicz // Polish Journal of Agronomy. — 2022. — 49. — DOI: 10.26114/pja.iung.487.2022.49.02.

24. Sanaei S. Systematic Assessment of Triticale-based Biorefinery Strategies: Techno-economic Analysis to Identify Investment Opportunities / S. Sanaei, P. R. Stuart // Biofuels, Bioproducts and Biorefining. — 2018. — 1. — DOI: 10.1002/bbb.1499.

25. Strang E. J. P. Variations in the Chemical Composition and Standardized Ileal Digestibility of Amino Acids in Eight Genotypes of Triticale Fed to Growing Pigs / E.J.P. Strang, M. Eklund, P. Rosenfelder // Journal of Animal Science. — 2017. — 4. — DOI: 10.2527/jas.2016.1238.

26. Widodo A.E. The Nutritional Value of New Varieties of High-yielding Triticale: Feeding Value of Triticale for Broiler Chickens / A.E. Widodo, J.V. Nolan, P.A. Iji // South African Journal of Animal Science. — 2015. — 1. — DOI: 10.4314/sajas.v45i1.9.

27. Zhu F. Triticale: Nutritional Composition and Food Uses / F. Zhu // Food Chemistry. — 2018. — 1. — DOI: 10.1016/j.foodchem.2017.09.009.