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Review

Triticale: A General Overview of Its Use in Poultry Production

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Abstract: Triticale, a hybrid of wheat and rye, is one of the most promising grain crops. In terms of productivity, the level of metabolizable energy, and the composition of essential amino acids, triticale surpasses rye and is not inferior to wheat. It is resistant to the most dangerous diseases and pests. In terms of nutritional value, triticale can compete with wheat, corn, sorghum, and barley. The presence, however, of antinutrients in triticale such as non-starch polysaccharides, alkylresorcinols, and trypsin inhibitors significantly reduces the biological value of this crop. In the global practice of compound feed production, there are many methods and technologies for processing grain raw materials to increase their nutritional value. Enzymatic treatment and extrusion technologies are worthy of special attention. The high content of triticale in the compound feed of poultry breeder flocks should be used effectively, taking into account the characteristics of triticale varieties and climatic conditions. An optimal triticale level in feed (15% for layer and broiler chicks) may improve body weight gain and reduce feed costs when raising replacement young stock. Layer breeder flocks fed a 20% triticale-based diet may have increased egg production, high viability, and flock uniformity. Producing triticale–soy and triticale–sunflower extrudates and supplementing the diet of poultry flocks with essential amino acids represent promising avenues for maximizing the benefits of triticale. Innovative methods of achieving this goal should be further developed and put into practice, particularly given the expansion of triticale's cultivation areas.

Keywords: triticale; poultry farming; feeds; chickens; amino acids; antinutrients; enzymatic treatment; extrudates

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1. Introduction

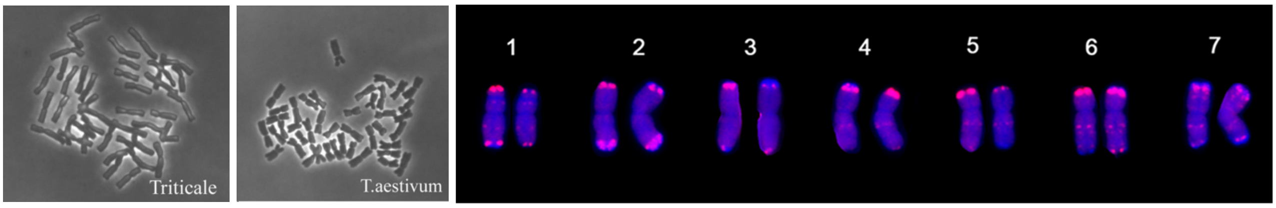
Poultry producers consistently face the challenges of increasing flock productivity and reducing production costs. Additional issues to be kept in mind include disease control (with a minimum use of antibiotics) for both animals and food crops, animal welfare, and environmental concerns. Balanced feeding plays one of the most crucial roles in poultry production. It needs to meet all the needs of the bird in accordance with age and productivity, providing a diet consisting of the required content of basic nutrients, energy, and biologically active substances including, proteins, amino acids, and carbohydrates [1–15]. Moreover, in order to expand the fodder base in the worldwide poultry industry, the sustained expansion of the harvesting area of cereal crops that are more resistant to climate change is essential [16–18].

Cereals are the main component of poultry feed. Conventionally, corn and wheat are most widely used for this purpose. Barley is utilized to a lesser extent, with rye and oats in smaller quantities. In recent years, the share of traditional cereals in compound feed for poultry has lowered in developed countries from 69–70% to 40–50%. This is due to both secondary ingredients of industrial processing and non-traditional feeds [16,19]. Alongside these conventional components, new cereal crops have appeared in poultry diets [20–23], such as sorghum and triticale (× *Triticosecale* Wittmack) (Figure 1). The latter is a promising crop and, with its rational use, can be a valuable compound feed ingredient and successfully partially replace the cereal crops traditionally used [17,23–31]. This becomes especially important in connection with the growing share of cereals that will be used for the production of biofuels, i.e., ethanol, biodiesel, and solid fuel pellets (e.g., [32–35]). The purpose of this review is to consider the nutritional, economic, and environmental benefits (as well as the drawbacks) of the rye–wheat hybrid triticale in poultry production.

Figure 1. Phenotypes of wheat (*Triticum aestivum*; left), rye (*Secale cereale*; middle), and their hybrid, triticale (right): (**a**–**c**) cultivation fields; (**d**–**f**) single ears; and (**g**) seeds. Image sources: (**a**) https://commons.wikimedia.org/wiki/File:Parcelle_De_bl%C3%A9_REGAIN_(Yvelynes)_Cl_J_Weber_(23787338000).jpg, CC-BY-2.0 (accessed on 10 February 2024); (**b**) https://commons.wikimedia.org/wiki/File:Rozh.jpg, Ivan Shishkin (1878), CC-PD-Mark (accessed on 10 February 2024); (**c**) https://commons.wikimedia.org/wiki/File:Triticalefeld.jpg, CC-BY-SA-3.0 (accessed on 10 February 2024); (**d**) https://commons.wikimedia.org/wiki/File:Frumento_Tenero_Rieti.jpg, CC-BY-3.0 (accessed on 10 February 2024); (**e**) https://commons.wikimedia.org/wiki/File:Secale_cereale_(Roggen)-2008b.jpg, CC-BY-SA-3.0,2.5,2.0,1.0 (accessed on 10 February 2024); (**f**) https://commons.wikimedia.org/wiki/File:LPCC-623-Espiga_de_triticale.jpg, CC-BY-SA-3.0 (accessed on 10 February 2024); and (**g**) https://commons.wikimedia.org/wiki/File:Wheat,_rye,_triticale_montage.jpg, PD USDA (accessed on 10 February 2024).

2. Triticale: Description, Significance, and Distribution

Triticale was first generated by crossing wheat (*Triticum*) with rye (*Secale*), and it belongs to the group of amphiploids [36] (Figures 1 and 2). By combining the chromosomal complements of two different botanical genera, wheat and rye, humans have managed, for the first time in the history of agriculture, to synthesize a new agricultural crop, which, according to experts, will become one of the leading grain crops in the near future [24,25,27,28,30,37]. Indeed, triticale is rapidly becoming a popular choice for poultry feed because of several desirable characteristics.

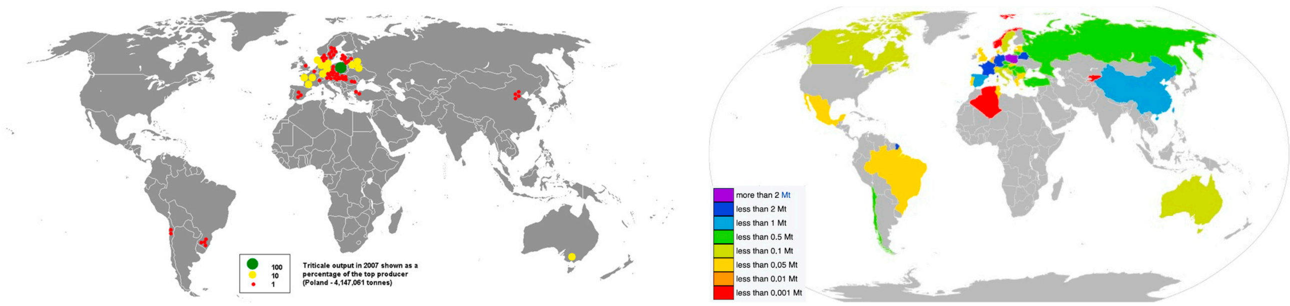


(**a**) (**b**) (**c**)

Figure 2. Karyotypes of triticale (**a**) and its parents, wheat (*Triticum aestivum*; (**b**)) and rye (*Secale cereale*; (**c**)). The fifth rye chromosome (5R) contains candidate genetic loci associated with important tolerance traits in triticale [38,39]. Image sources: (**a**) https://commons.wikimedia.org/wiki/File:Karyotype_of_Triticale.png, CC-BY-2.0 (accessed on 10 February 2024); (**b**) https://commons.wikimedia.org/wiki/File:Karyotype_of_wheat_(Triticum_aestivum).png, CC-BY-2.0 (accessed on 10 February 2024); and (**c**) https://commons.wikimedia.org/wiki/File:Karyotype_of_Austrian_rye_(Secale_cereale).png, CC-BY-2.5 (accessed on 10 February 2024).

Triticale can adapt easily to a range of diverse growing conditions, and it is, thus, a reliable crop for poultry feeding in a range of situations. The studies of Nielsen et al. [40] and Faccini et al. [41] highlighted the ability of triticale to tolerate multiple climatic conditions and soil types. This ability to adapt means that triticale can be available and affordable in many marketplaces, protecting it from price fluctuations. Triticale attracts special attention due to the fact that it is grown in many agricultural areas of the world. Its introduction and cultivation are one of the most promising agricultural growth sectors associated with the expansion of the use of non-traditional feed components for poultry. It has become widespread in the countries in Eurasia but less so in North and South America, Africa, and other regions (Figure 3). This new sector of agriculture is also driven by climate change, particularly on the Eurasian continent where large areas of land have become more amenable for growing grain crops. Triticale is able to surpass both of its parent forms in terms of important indicators such as yield and nutritional value [42–45]. Triticale, like all cereals, is richest in carbohydrates and also contains proteins, fats, mineral components, and biologically active compounds [42–44,46,47].

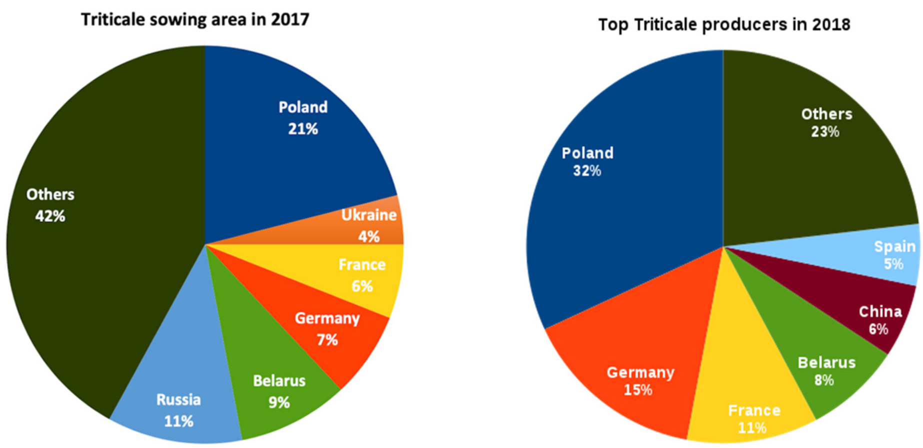
Triticale is resistant to many phytopathogenic diseases characteristic of cereals [48], e.g., fusaria [49–53]. Among fungal pathogens, wheat stem rust, caused by *Puccinia graminis* f.sp. *tritici* (Pgt), appears to be one of the most serious for cereal crops. However, a new synthetic tetraploid triticale obtained by crossing rye (*Secale cereale*) with einkorn wheat (*Triticum monococcum* spp. *monococcum*), a carrier of the stem rust resistance gene *Sr35*, has been described [54]. According to several observations [51–53], the amount of tetraploid triticale grain with internal infection did not exceed 30%, while, for wheat, this indicator reached 90%. Triticale is also not affected by powdery mildew, yellow rust, nor brown rust [27,54–59]. According to triticale producers [60–69], its spring varieties provide an environmentally friendly stable grain yield due to immunity and tolerance to disease. They are grown without the use of fungicides and are able to compete with annual weeds. This eliminates the need to use herbicides on crops [50,70–76]. In terms of resistance to adverse soil, climatic conditions, and the most dangerous diseases, triticale is not inferior to rye and surpasses wheat [39,48,50,77–80]. Another great advantage of triticale is its significant potential for frost and winter tolerance, ensuring sufficient overwintering [27,38,39,48,54,62,66,69,81–83]. Recent triticale genome-wide studies revealed quantitative trait loci and candidate genes associated with abiotic (freezing) and biotic (pink snow mold) stress tolerance that are located on chromosomes such as 2B (descendent from wheat) and 5R (inherited from rye; Figure 2c) [38,39]. Spring triticale is a very promising crop for ensuring the stable production of food and technical and fodder grain in different climatic zones [60,63,64,67,70,72,74,75,84,85]. This is especially important for difficult weather conditions that, on average, once every four years, lead to the death of large areas of winter grain crops [37,61,65,68,86,87]. Reseeding these areas with fresh grain crops makes it possible to maintain grain balance.



(**a**) (**b**)

Figure 3. Global distribution of triticale output by producers in 2007 (**a**) and 2018 (**b**). (**a**) As a percentage of the top producer (Poland, 4.15 Mt); (**b**) triticale producers by production quantity (in Mt). Image sources: (**a**) https://commons.wikimedia.org/wiki/File:2007triticale.png, PD-user (accessed on 10 February 2024); (**b**) https://commons.wikimedia.org/wiki/File:Top_Triticale_producers_2018.svg, CC-BY-SA-4.0 (accessed on 10 February 2024).

According to FAO data (as quoted in [19]), the harvesting area of triticale in the world in 2017 was 5.6 million hectares. The majority of it was in Poland (1.2 million ha), Russia (600 thousand ha), Germany (404 thousand ha), France (331 thousand ha), Belarus (500 thousand ha), and Ukraine (200 thousand ha) [41,63,67] (Figure 4). This area's growth continues (Figure 3), and it can be predicted that, in the coming years, triticale will occupy one of the top places among cereal crops.



(**a**) (**b**)

Figure 4. Percentages of the world's triticale sowing area (**a**) and production (**b**) by top countries. Image sources: (**a**) authors' own design; and (**b**) https://commons.wikimedia.org/wiki/File:Top_Triticale_producers_2018.svg, CC-BY-SA-4.0 (accessed on 10 February 2024).

The yield of triticale varies from 3.05 t/ha to 7.2 t/ha in different fields, depending on the fertilizer and mineral background [37,70,72,74,75,86,87]. In many places, triticale significantly surpasses wheat and rye in terms of grain yield, protein content, and its harvest per hectare [61,65,68]. Triticale, barley, and rye grains contain more crude protein and a better amino acid profile than corn, including a higher content of lysine, methionine, threonine, and tryptophan [48,88,89].

3. The Nutritional Value of Triticale

One of the key advantages of triticale as a feed for commercial chickens is its superior nutritional value compared to other crops. It has considerable potential to improve the nutritional value of diets fed to broiler and layer chickens [19,90–92]. Triticale has a balanced profile of protein, carbohydrates, and dietary fiber and is, thereby, well suited to fulfil the daily dietary requirements of commercial flocks [42–44,46,47]. The relatively high protein content in triticale helps to promote optimal growth, while the carbohydrates contained therein provide a crucial energy source [88].

3.1. Metabolizable Energy, Crude Protein, Starch, and Fiber Content

A distinctive feature of triticale is its relatively high crude protein content and metabolizable energy value (13.5–13.7 MJ/kg) [88]. With respect to the metabolizable energy level, triticale surpasses rye and is not inferior to wheat [19,26,28,29,31]. Its crude protein content, depending on the variety and agro-ecological growing conditions, ranges from 8 to 16%. In terms of crude protein content, triticale grain surpasses not only rye, oats, and barley but often wheat as well. In modern newly created varieties of triticale, however, this indicator, due to increased starch content, has slightly lowered values and does not exceed the level of wheat [93]. Depending on the year of cultivation, the crude protein content in different varieties of spring triticale varies within approximately the same limits (12–13%), being similar to that of wheat. In winter triticale varieties, compared to spring triticale, the crude protein content is 2–3% lower (i.e., 10–11%). In some samples of winter triticale grown with a minimal use of fertilizers, the crude protein content ranges from 7 to 8% and is similar to rye [19,26,28,29,31].

The main component of triticale grain, like other cereals, is starch [94], accounting for $\frac{3}{4}$ of the grain's weight [95]. It is known from the literature [19,94] that grain density declines with a rise in protein content and, conversely, rises via an increase in starch content. The relative content of starch in triticale is lower and that of protein is higher than those of rye and wheat [94,96,97]. Unlike wheat and rye, triticale starch is characterized by a low amylase content (23.7%). In terms of density (at 30 °C), triticale starch exceeds rye starch (1.4465 vs. 1.4209) but is slightly less than the starch of soft wheat (1.4832) [98]. Moreover, the overall digestibility of triticale (79.8%) is higher than that of oats (79.4%) and barley (75.0%), with, specifically, a protein digestibility (92%) exceeding that of wheat (90%) and rye (84%) [77,79,80].

Gluten from the flour of this crop is of a high quality, and it is, thus, often used to prepare varietal mixtures with low-quality wheat flour. From the flour of modern triticale varieties, the food industry has also begun to bake high-quality bread, biscuits, and other confectionery products [48,84,85,99–101].

In triticale, the total dietary fiber content ranges between 13 and 16% [98]. The major components of dietary fiber are arabinoxylan (average 6.8%), fructan (average 2.3%), cellulose (average 2.1%), Klason lignin (average 1.6%), and β-glucan (average 0.7%) [98]. Overall, cellulose has a rather small proportion in triticale [19]. The dietary fiber profile and molecular weight distribution of the extractable dietary fiber components in triticale grains are considerably closer to those of wheat than rye [102]. Both cultivar and location have an impact on the content of total dietary fiber and its components [98]. For instance, cellulose, in one of the studies [19], occupied an average of 2.7% (from 2.4 to 3.3%), with the differences between winter and spring triticale varieties being insignificant.

3.2. Amino Acid Composition

The nutritional value of protein depends on amino acid composition and, specifically, the balance of essential amino acids [42,103,104]. The triticale grain, as well as other grain crops, contains the most important and indispensable amino acid, lysine [105]. Therefore, its content in triticale can serve as one of the indicators of the overall protein quality of this grain. In this respect, the triticale grain has an increased lysine content (1.56 g/kg), i.e., almost 1.4 times more than that of wheat and twice as much as corn [9,106,107]. In terms of the lysine content (about 3% of the total protein amount), triticale can surpass wheat (by 16–20%) [108,109]. Indeed, the content of lysine in improved lines of triticale was originally close to that of high-lysine corn [110]. In comparison to wheat, the triticale grain also contains more free essential amino acids such as valine, leucine, and others [103,111].

3.3. Antioxidants and Minerals

Triticale grain has a relatively high content of B-group vitamins as well as antioxidants, including vitamin E and phenolic acids. In particular, triticale contains water-soluble vitamins B_1 (0.4 mg/kg dry matter (DM)), B_2 (0.1 mg/kg DM), B_3 (1.4 mg/kg DM), B_5 (1.3 mg/kg DM), B_6 (0.1 mg/kg DM), and B_9 (73.0 µg/kg DM). Out of the fat-soluble vitamins, only vitamin E is present (about 0.9 mg/kg DM) [6,10,14,112–115]. A high ash content is also characteristic of triticale grains [99], and the main mineral substances in triticale are phosphorus and potassium.

4. Triticale Content in Feed

The effectiveness of triticale as a fodder crop depends on the level of input, variety, and application conditions [20,44,116–119]. Triticale is included in the compound feed for livestock [17] including cattle, pigs, sheep [3,120–122], and, specific to this review, poultry [24–31,123]. It partially replaces wheat, corn, and sometimes legumes; however, there are varying opinions in the data regarding the ratio of triticale to use, ranging usually from 15 to 60% [26,28,29,31,47,124,125] (Table 1).

Table 1. Selected poultry feeding trials using triticale.

Triticale Content in Feed	Type of Poultry	Effect	References
15%	layer breeders (chicks)	Increased feed conversion, improved viability	[24,25,27,28,30]
20%	layer breeders (adults)	Increased egg production (by 2.5%), egg yield (by 4.6%), egg hatchability (by 2.4%)	[24,25,27,28,30]
40% (triticale–sunflower extrudate)	layer breeders (adults)	Increased egg production (by 3–5%)	[126]
50% (triticale–soy extrudate)	layer breeders (adults)	Increased egg hatchability (by 1.86–2.11%)	[126]
20 to 69%	broiler chickens	No negative effect on growth and development compared to corn	[127]
70% corn replaced with triticale	laying hens	Did not impair performance	[128]
40% corn replaced with triticale	broiler chickens	Did not reduce growth rate	[129]
50% corn replaced with triticale	broiler chickens	Did not reduce growth rate	[130]
50 or 70%	laying hens (White Leghorn)	Decreased egg performance, increased feed consumption	[131]
15%	broiler chickens	Optimal content of triticale in the diet	[132]
35% (triticale–sunflower extrudate)	replacement chicks (laying hens)	Reduced feed consumption per 1 kg body weight gain (by 2.4 and 5.4% in the first and second months of rearing), improved flock uniformity (by 0.6%)	[122,133]

According to the studies of Pettersson [129] and Charalambous et al. [130], the replacement of 40% and 50% of corn with triticale grains did not reduce broiler growth intensity and feed efficiency. Indeed, only the complete replacement of corn lowered chicken performance indicators. It has been determined [90–92,132] that the optimal triticale content in the diet of broilers was around 15%, suggesting that a further increase in the proportion of triticale could lead to a reduction in body weight and a rise in feed costs.

Brzóska [128] stated that 70% of corn in the diet of laying hens can be replaced with triticale without a deterioration in performance. At the same time, according to Leeson and Summers [131], when 50% or 70% of triticale was included in the compound feed of White Leghorn laying hens (regardless of the diet structure), egg production decreased and feed consumption increased. Significant differences between breeds of laying hens in terms of body weight gain, hen feed consumption, egg weight, and cholesterol content in the eggs were found when they were fed wheat, triticale, and rye [134]. The identification of the optimal triticale level in the diet of poultry, however, requires further research. Significant discrepancies in the results of various studies regarding optimal triticale levels can be related to both the methodology of conducting experiments and the characteristics of triticale varieties grown under different conditions and in different countries [93]. For instance, Landfried [116] established that the proportional replacement of 60% of wheat with triticale had no negative effect on poultry performance. When isoprotein rations were included due to wheat replacement, however, performance significantly deteriorated.

For poultry breeder flocks, a high triticale content in compound feed should be utilized, with consideration for variety characteristics and climate [24,25,27,28,30,135,136]. For example, optimal triticale levels in compound feed (up to 15%) contributed to increased body weight gain, reduced feed costs, and a normal viability when rearing layer breeder pullets. Adult layer breeder chickens fed up to 20% of triticale presented an increase in their egg laying (by 1.5–2%), high viability (96.7–100%), and flock uniformity [19]. Male breeder turkeys fed triticale (8.5%) had improved tenderness and shear value of cooked breast meat in contrast to meat from birds fed diets consisting of corn–soy or triticale–soy [137].

5. Levels of Limiting Amino Acids in Triticale-Based Diets

For the efficient utilization of feed, diets should be used that are balanced in terms of both the amount and the ratio of amino acids. A bird cannot store amino acids, so it should receive them continually and in the right amount; excessively consumed amino acids are deaminated [138–140]. The degree of assimilation of amino acids from specific feeds has a great influence on the efficiency of feed consumption by poultry. Accordingly, the higher the degree of assimilation, the more accessible amino acids are from a particular feed. There is, thus, a direct relationship between the quality of amino acid exposure, productivity, and the health of poultry [141,142].

When using triticale, the balancing of compound feed by amino acids, vitamins, and minerals is also crucial [28,143–145]. There are few data in the literature, however, regarding limiting amino acids when using triticale-based rations, and the data obtained in various experiments on this issue are also quite contradictory. Some authors [42,146,147] reported that an increased lysine supplementation in diets high in triticale directly improved the live weight of piglets, while methionine inhibited their growth. Shimada and Cline [148] noted that the first limiting amino acid in triticale diets for rats is lysine, and the second is threonine. Similar results were obtained in pigs [105,146], and a positive effect of elevating the methionine level when using triticale was also not found. Herein, the opposite results were obtained in broilers: when adding lysine to compound feed with a high triticale content, the body weight of broilers did not increase, while the addition of methionine improved growth [43,47,149]. At the same time, the increased lysine level in compound feed with triticale led to a greater performance of chickens and egg weight. Such a discrepancy in the results can probably be related to certain peculiarities of triticale, e.g., varieties and agro-climatic conditions of cultivation [16,18], as well as the type of diet in which triticale was included.

Thus, there is a need for further research on the optimal level of limiting amino acids in triticale-based rations for specific regions and varieties regionalized in them, taking into account the prevailing types of diets (corn–soybean, wheat–sunflower, etc.). In this regard, not only methionine and lysine deserve attention but also threonine, which can be the second limiting amino acid in compound feed with triticale [19,105].

6. Methods of Leveling Antinutrients in Triticale-Based Feed for Poultry

6.1. Enzymatic Treatment

Despite its many advantages as a food crop, triticale contains many antinutritional substances, such as non-starch polysaccharides (NPS), alkylresorcinols, and trypsin inhibitors that can reduce its biological value significantly [19,48,150]. The presence of these substances impedes its more widespread use in poultry feeding; however, with the help of recent technological innovations, the impact of these antinutritional factors can be overcome or at least mitigated [46].

One of the promising methods capable of breaking down NPS in triticale is the application of enzyme preparations [151,152]. The main negative effect of NPS in triticale is related to its ability to elevate the viscosity of chyme. This, in turn, depends on NPS polymer structure. Splitting such polysaccharides into smaller fragments should, in theory, prevent the creation of a mesh structure and jelly-like chyme, significantly reducing the antinutritive properties. The effect of additives such as enzyme preparations [153] is difficult to estimate when using components in compound feed that are difficult to hydrolyze (barley, rye, millet, sorghum, triticale, peas, sunflower, rapeseed, flax, etc.), since their use in a large amount has a detrimental effect on feed assimilation and poultry performance [154–158].

Enzymes, unlike hormones and biostimulants, are not added to act on the bird's body directly but on the components of compound feed in the gastrointestinal tract [19,159,160]. For example, cellulases catalyze the hydrolysis of the cellulose macromolecules in feed to dextrins and glucose, whereas proteases such as trypsin catalyze the hydrolysis of proteins to amino acids [161,162]. To increase the digestibility and availability of nutrients in compound feed with reduced consuming ability (barley–wheat), therefore, it is recommended to introduce enzyme preparations containing a complex of amylolytic, pectolytic, cellulolytic, and proteolytic enzymes [163,164].

In poultry farming, feed enzyme preparations are widely used [155,157,158] and also contain accompanying organic and mineral substances. These include the remains of the nutrient medium of microorganisms, various fillers and stabilizers, preservatives, and products of the vital activity of microorganisms (amino acids, vitamins, organic acids, etc.). However, the main components of enzyme additives are hydrolytic enzymes (cellulases, xylanases, β-glucanase, α-amylases, proteases, pectinases, phytase, etc.) that play an important role in the assimilation of feed nutrients [97,156,165–168] and are mainly extracted by microbial synthesis using fungi and bacteria.

In numerous studies, it has been established that the inclusion of enzyme preparations with xylanase activity in compound feed based on wheat, rye, and triticale contributed to the better development of chickens and better digestion of dry matter, protein, fat [167–171], and crude fiber [163]. According to García et al. [172], the use of enzyme preparations with xylanase and β-glucanase activity in compound feed with barley contributed to a reduction in chyme viscosity, increased nutrient assimilation and the average daily gains, and cut feed costs. Herewith, some authors found a positive effect on the average daily body weight gain of chickens but did not note an improvement in feed conversion. Moreover, the use of enzyme preparations did not give positive results in a number of investigations. For instance, Brenes et al. [156] did not find a positive effect of enzymes on the productivity of chickens when using wheat and rye.

In a number of studies, it was established that xylanase was effective only when using coarsely ground wheat or whole wheat [156,165,166]. That is, there was an increase in the body weight of chickens by 21% when the enzyme preparation was included in the diet with 7% rye, but this increase was only 11% when the chickens were fed with a limited fodder amount. In addition, the variety and growing conditions of cereals are of a significant importance. In particular, according to Partridge [173], the application of enzyme preparations in rations with some wheat varieties was much more effective than for other varieties. Under the influence of the enzyme preparation, there was an elevation in the body weight of chickens from 2 to 41% depending on the barley variety.

According to Pettersson and Åman [174], when using triticale with a low, medium, and high content of pentosans (5, 6, and 7%, respectively) in broiler feed, the effect of the enzyme preparation was practically absent at a low content of pentosans. The highest effect was observed when there was a greater content of pentosans. In addition, enzymes that break down NPS [152] can have a different structure depending on their origin (from bacteria or microscopic fungi of specific species and strains) and the effect of their use depends on this. Moreover, depending on their origin, enzymes cleave NPS in different ways and, as a result, can even elevate the viscosity of a solution, i.e., increase the negative effect of NPS [165,175].

The high content of carbohydrate fractions in feed, which are difficult to hydrolyze, reduces the efficiency of the use of nutrients in feed mixtures. When using compound feed with high levels of triticale containing antinutritional substances, treatment of the feed with the appropriate amount of enzyme preparations is paramount [159,160]. The main biological activity of enzyme preparations in this context can be summarized as follows [19]:

- They destroy the walls of plant cells, increasing the availability of starch, protein, and fat, which are included in their composition, for the action of enzymes of the gastrointestinal tract;
- They increase the digestibility of nutrients and improve their absorption in the small intestine [169];
- They eliminate the negative effect of antinutritional factors that affect the absorption and use of nutrients [46];
- They improve the microbiological environment of the intestines by reducing viscosity and increasing the level of monosaccharides [166].

Thus, the recognition of antinutrients in triticale, including NPS, alkylresorcinols, and trypsin inhibitors, necessitates a careful analysis of the crop's nutritional characteristics. This acknowledgment helps to create a fair assessment of how triticale should be used in poultry feeding.

Another promising way to increase the fodder value of cereals and, in particular, triticale is the use of various processing techniques [176]. For instance, Preston et al. [177] found that pelleting wheat-based feed improved chicken performance, with hot pelleting having a higher chyme viscosity compared to cold pelleting. Venäläinen et al. [178] noted the improvement in the fodder qualities of barley after passing it through rollers. According to Perttilä et al. [114], barley ensiling increased the metabolizable energy and digestibility of dry matter for broilers more effectively compared to passing it through rollers. Barley expansion contributed to a decline in chyme viscosity and an improvement in body weight gain and feed conversion, not only in comparison with native but also with micronized barley.

6.2. Extrusion Treatment

Extrusion is one of the most effective and affordable technological methods of preparing grain feed for poultry in order to increase the assimilation of nutrients [136,179,180]. Hereby, an additional area worthy of consideration is cereal extrudates enriched with soy and sunflower. Due to higher energy and protein nutrition values, these are valuable raw materials for the compound feed of young and adult birds [181]. Using layer breeders [19], it was shown that the maximum levels of inclusion of extrudates in the composition of a full, rational, and balanced compound feed were within 40–50% (for triticale–sunflower and triticale–soy extrudates). The use of compound feed with this level of extrudates contributed to the normalization of metabolic processes in the poultry body and had a positive effect on the performance of chickens, increasing egg production by 3–5% and egg hatchability by 1.86–2.11% [19]. Exploration of this approach, however, is further needed, and more studies on this issue will be important and relevant in the coming years.

Triticale extrusion technology includes a series of successive grain treatments [19], as outlined below. At the beginning of the extrusion process, appropriately prepared grain (or grit) is fed to the extruder body, which is a hermetically sealed chamber in which the screw rotates. When the grain is repeatedly compressed by the screws of the auger, it is compacted and heated as a result of frictional forces. The moisture contained in it changes to a vapor state, and pressure is created, the value of which reaches 3–5 MPa. Under the influence of mechanical and physical deformation, temperature (120–180 °C), and pressure, the raw material changes from a brittle state to a highly elastic one. At the same time, the structure of grain biopolymers changes: proteins are denatured; starch is pasteurized; and the cellulose–lignin complex is destroyed. That is, deep biochemical processes occur, which lead to a significant improvement in the assimilation of feed in the bird's body. These processes continue in the homogenization zone, where the product is already in a viscous state [19].

The main and most important changes in nutrients take place in the extrusion ("explosion") zone when the heated viscous mass is pressed through the dies (short outlet holes) and abruptly transferred from the high-pressure zone to the atmospheric one. At the same time, the energy accumulated by the product is released at a speed approximately equal to the speed of the explosion [182]. This leads to the "explosion" of the product. As a result of this, a new (extruded) feed with a microporous structure is created, which makes it more accessible to the action of digestive enzymes [19].

During extrusion, changes occur in the biopolymer complexes of the grain. Starch is hydrolyzed, as a result of which its solubility increases, the content of dextrins and amylose grows, and the amount of sugars changes [19]. In different cereals, these processes occur differently due to the natural features of the grain structure of each culture. For instance, when comparing changes in the carbohydrate complex in corn and barley groats due to extrusion, it has been noted [183–185] that the mass fraction of dextrins in corn after extrusion increased by 105 times and in barley by 40 times; amylose in corn extrudate increased by 43 times and in barley by 79 times.

In the process of extrusion, the structure of protein molecules is destroyed, the number of peptides and free amino acids increases, and, as a result, their digestibility improves [19]. Hereby, antinutrients are also inactivated, most of which are of a proteinaceous nature (these are inhibitors of proteases, hemagglutinins, lipoxidase, lipoxygenase, etc.). Excessive or prolonged overheating for the purpose of inactivating antinutrients can lead to a reduction in the availability of amino acids in the extrudate, which will be indicated by an abrupt decline in the proportion of water-soluble proteins [103].

When passing through the body of the extruder and at the moment of "explosion", the structure of fat cells is destroyed, and intercellular membranes are torn. This leads to an increased amount of released (available) oil, due to which the energy value of the extrudates of oil crops as well as that of mixed extrudates of cereal crops with oil crops rises. Lipids retain their properties during extrusion, as oxidizing enzymes (lipases and lipoxygenases) are inactivated, which contribute to product oxidation and longer storage [19].

There are dry and wet (with a preliminary steaming of raw materials) extrusion technologies. The dry extrusion process lasts up to 30 s. During this period, raw materials are crushed under the influence of deforming loads, exposed to high temperature and pressure, disinfected, and dehydrated (with the output moisture content of the grain being 12–14%, and that of the cooled extrudate 8–10%), and they increase in volume [19]. The mass of the same volume of ground grain or grain mixture should be higher than the mass of the extruded product. This should be four or more times higher for peas and corn and two, three, or more times higher for wheat, barley, and other crops [45,186,187].

The quality of extrudates depends on many factors, including the following: the composition of the raw material, its humidity, the method of preliminary preparation, the temperature, the duration and intensity of the mechanical impact on the raw material, the design of the screw, etc. [187]. Extrudates of grain feed are lighter in color than the raw material and have a pleasant bready taste and smell. After grinding, they contain a little dust-like fraction, have good flowability, and are easily mixed with other components of compound feed [45,147].

In the rations for poultry of all age groups, extruded grains are not yet as widely used as in animal husbandry. Perhaps this is due to the fact that poultry feed mainly uses easily digestible corn and wheat that, in most cases, do not require additional processing, and the use of components such as barley, triticale, rye, peas, etc., is limited by their high levels of cellulose, β-glucans, pentosans, trypsin inhibitors, and other antinutrients [19]. The extrusion of these cereals allows to partially neutralize the existing antinutritional factors and, due to the porous structure of the extrudates, obtain products with a better availability of polysaccharides and proteins for digestive enzymes, i.e., to improve the nutritional value of feed, even in the process of preparing it for feeding and, thus, expand the limits of its use in poultry diets [136].

7. Conclusions and Prospects

Triticale has a range of advantages as a poultry foodstuff compared to other crops. These include its high yield, nutritional value, favorable amino acid composition, high starch content, high fullness and weight of the grain, adaptability to climatic and soil conditions, and its positive impact on the environment. Triticale provides considerable environmental benefits in terms of sustainable agricultural practices [27,48]. Despite several advantages of triticale, however, the practical implications for poultry farmers have a series of issues (e.g., limiting amino acids and antinutrients) that require further research.

Contemporary triticale varieties among grain crops are an affordable and valuable fodder in various regions of the world, and their use in animal and poultry feed is, thereby, gradually increasing [93]. This contributes to the expansion of the fodder base, increasing multicomponent rations and reducing the competition for wheat. However, according to the literature, depending on the level of triticale in a diet, the productivity of poultry may change (increase or decrease) compared to diets based on wheat, and this is one more area that requires further investigation. These limitations of the reviewed studies and the corresponding variation in the results are probably related to the methods of conducting the experiments, different triticale varieties, and the conditions of their cultivation in different countries [93].

The use of additional feed additives is effective in some cases and has no effect in others. Moreover, it should be noted that the effectiveness of using triticale largely depends on the content of antinutrients in it. In this respect, the data obtained in various experiments can be contradictory at times.

Considering the prospective use of triticale in poultry farming and the expansion of its cultivation areas, it is essential to develop and implement new methods to use it effectively when it is present in a high proportion in the compound feed of poultry breeder flocks [24,25,27,28,30,136]. New developments will employ enzyme preparations, taking into account the characteristics of different triticale varieties and climatic conditions, the production of triticale–soy and triticale–sunflower extrudates, and the enrichment of diets using amino acids.

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References

1. Wu, G.; Bazer, F.W.; Dai, Z.; Li, D.; Wang, J.; Wu, Z. Amino acid nutrition in animals: Protein synthesis and beyond. *Annu. Rev. Anim. Biosci.* **2014**, *2*, 387–417. [CrossRef]
2. He, W.; Li, P.; Wu, G. Amino acid nutrition and metabolism in chickens. *Adv. Exp. Med. Biol.* **2021**, *1285*, 109–131. [CrossRef]
3. Grela, E.R.; Kowalczuk-Vasilev, E.; Świątkiewicz, M.; Skiba, G. Barley, triticale, or rye? The type of grain can affect the growth performance and meat quality of sustainable raised pigs. *Animals* **2023**, *13*, 1331. [CrossRef]
4. Ibatullin, I.I.; Kryvenok, M.Y.; Panasenko, Y.O.; Ilchuk, I.I. Digestibility of feed nutrients and methionine balance in the body of chickens of the parent flock at different levels of methionine in the diets. *Sučasne Ptahìvnictvo Mod. Poult. Farming* **2013**, *5*, 2–5. (In Ukrainian)
5. Otchenashko, V.V. Productivity of meat quails fed compound feeds with different levels of crude protein. *Naučnye Tr. SWorld Sci. Pap. SWorld* **2013**, *4*, 79–87. (In Ukrainian)
6. Ionov, I.A. Vitamin E as a means of improving the quality of poultry products and the antioxidant status of the body. *Vìsnik agrarnoï nauki Bull. Agric. Sci.* **2010**, *4*, 37–39. Available online: https://agrovisnyk.com/oldpdf/visnyk_04_2010.pdf#page=37 (accessed on 20 November 2023). (In Ukrainian)
7. Lemesheva, M.M. Poultry Feeding. Slobozhanshchyna: Sumy, Ukraine, 2003. (In Ukrainian)
8. Fagundes, N.S.; Milfort, M.C.; Williams, S.M.; Da Costa, M.J.; Fuller, A.L.; Menten, J.F.; Rekaya, R.; Aggrey, S.E. Dietary methionine level alters growth, digestibility, and gene expression of amino acid transporters in meat-type chickens. *Poult. Sci.* **2020**, *99*, 67–75. [CrossRef]
9. Tarasewicz, Z.; Gardzielewska, J.; Szczerbińska, D.; Ligocki, M.; Jakubowska, M.; Majewska, D. The effect of feeding with low-protein feed mixes on the growth and slaughter value of young male Pharaoh quails. *Arch. Anim. Breed.* **2007**, *50*, 520–530. [CrossRef]
10. Surai, P.F.; Fisinin, V.I. Antioxidant Systems of the Body: From Vitamin E to Polyphenols and Beyond. In Proceedings of the 35th Western Nutrition Conference, Edmonton, AB, Canada, 24–25 September 2014; pp. 265–277. Available online: https://www.cabidigitallibrary.org/doi/pdf/10.5555/20163076348 (accessed on 9 February 2024).
11. Lemesheva, M. A feed mixture of varying structure for turkeys. *Pticevodstvo Poult. Farming* **1991**, *11*, 11–13. Available online: https://www.cabidigitallibrary.org/doi/full/10.5555/19931456675 (accessed on 9 February 2024). (In Russian)
12. Wilkinson, S.J. Big Data for Poultry—What Is Possible? In Proceedings of the 29th annual Australian Poultry Science Symposium, Sydney, Australia, 4–7 February 2018; Volume 29, pp. 152–158. Available online: https://poultry-research.sydney.edu.au/wp-content/uploads/2019/08/APSS-2018-Proceedings-Final.pdf#page=167 (accessed on 10 February 2024).
13. Fearnside, P.M. Soybean cultivation as a threat to the environment in Brazil. *Environ. Conserv.* **2001**, *28*, 23–38. [CrossRef]
14. Zerjal, T.; Härtle, S.; Gourichon, D.; Guillory, V.; Bruneau, N.; Laloë, D.; Pinard-van Der Laan, M.H.; Trapp, S.; Bed'hom, B.; Quéré, P. Assessment of trade-offs between feed efficiency, growth-related traits, and immune activity in experimental lines of layer chickens. *Genet. Sel. Evol.* **2021**, *53*, 44–60. [CrossRef]
15. Pesti, G.M. Impact of dietary amino acid and crude protein levels in broiler feeds on biological performance. *J. Appl. Poult. Res.* **2009**, *18*, 477–486. [CrossRef]
16. Kyrychenko, V.V.; Maklyak, K.M.; Varenyk, B.F.; Kutishcheva, N.M.; Trotsenko, V.I. The practical characteristics expressing of three-linear sunflower hybrids in different agro-climatic zones of Ukraine. *Vìsn. Sums'kogo Nac. Agrar. Unìv. Ser. Agron. Bìol. Bull. Sumy Natl. Agrar. Univ. Ser. Agron. Biol.* **2016**, *9*, 129–133. Available online: https://web.archive.org/web/20220325181928/http://repo.snau.edu.ua/bitstream/123456789/5660/1/32.pdf (accessed on 20 November 2023). (In Ukrainian)
17. Kchaou, R.; Benyoussef, S.; Jebari, S.; Harbaoui, K.; Berndtsson, R. Forage potential of cereal–legume mixtures as an adaptive climate change strategy under low input systems. *Sustainability* **2023**, *15*, 338. [CrossRef]
18. Masenya, T.I.; Mlambo, V.; Mnisi, C.M. Complete replacement of maize grain with sorghum and pearl millet grains in Jumbo quail diets: Feed intake, physiological parameters, and meat quality traits. *PLoS ONE* **2021**, *16*, e0249371. [CrossRef]
19. Gaviley, O.V. Efficiency of the Use of Triticale in Fodder for Breeding Chickens. Ph.D. Thesis, State Poultry Research Station of NAAS, Kharkov State Zooveterinary Academy, Kharkiv, Ukraine, 2018. Available online: https://hdzva.edu.ua/svr/wp-content/uploads/sites/34/2018/06/dysertatsiya-gavilej.pdf (accessed on 20 November 2023). (In Ukrainian)

20. Smith, R.L.; Jensen, L.S.; Hoveland, C.S.; Hanna, W.W. Use of pearl millet, sorghum, and triticale grain in broiler diets. *J. Prod. Agric.* **1989**, *2*, 78–82. [CrossRef]
21. Zhukorskyi, O.; Prytulenko, O.; Tereshchenko, O.; Bratyshko, N. The Presence of Soybean, Triticale and Sorghum in Compound Feed for Poultry is Fully Justified. *Zerno i khlib Grain Bread* **2012**, *2*, 14–16. Available online: https://www.researchgate.net/publication/342832208_Zukorskij_O_Pritulenko_O_Teresenko_O_Bratisko_N_Prisutnist_soi_tritikale_j_sorgo_v_kombikormah_dla_ptici_cilkom_vipravdano_Zerno_i_hlib_-_2012_-_No_2_-_S_14-16?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InByb2ZpbGUiLCJwYWdlIjoic2VhcmNoIiwicG9zaXRpb24iOiJwYWdlSGVhZGVyIn19 (accessed on 20 November 2023). (In Ukrainian)
22. Różewicz, M. Production, use and efficiency of utilising grains of various cereal species as feed resources for poultry production. *Pol. J. Agron.* **2019**, *38*, 66–74. [CrossRef]
23. Farahat, M.; Badawi, M.; Hussein, A.; Attia, G. Effect of replacing dietary corn by sorghum on the growth performance, shank skin pigmentation, carcass traits, caecal microflora and nutrient digestibility of broiler chickens. *Int. J. Poult. Sci.* **2020**, *19*, 424–431. [CrossRef]
24. Bratishko, N.; Gaviley, Y.; Pritulenko, O.; Tereshchenko, A. Triticale in compound feed for chicken breeders. *Pticevod. Poult. Farming* **2008**, *9*, 30–32. Available online: https://www.elibrary.ru/item.asp?id=11566990 (accessed on 20 November 2023). (In Russian)
25. Bratishko, N.I.; Gritsenko, R.B.; Pritulenko, O.V.; Tereshchenko, A.V. Triticale in Compound Feed for Breeding Chickens. *Sučasne Ptahìvnictvo Mod. Poult. Farming* **2008**, *4*, 3–4. Available online: https://www.researchgate.net/publication/342764397_Bratisko_NI_Gricenko_RB_Pritulenko_OV_Teresenko_AV_Tritikale_v_kombikormah_dla_plemennyh_kur_Sucasne_ptahivnictvo_Naukovo-virobnicij_zurnal_-_Kiiv_Nacionalnij_agrarnij_universitet_Institut_ptahivnictv (accessed on 20 November 2023). (In Russian)
26. Bratishko, N.I.; Tereshchenko, A.V.; Pritulenko, O.V.; Gaviley, E.V. Influence of Triticale on the Productivity of Chickens When it Is Included in Compound Feed in Combination with Corn or Wheat. In *Advances in Modern Poultry Science, Proceedings of the 16th International Conference, Sergiyev Posad, Russia, 19–21 May 2009*; Fisinin, V.I., Egorov, I.A., Vasilyeva, T.V., Eds.; WPSA—Russian Branch, RAAS, All-Russia Poultry Science and Technology Institute: Sergiyev Posad, Russia, 2009; pp. 83–84. (In Russian)
27. McGoverin, C.M.; Snyders, F.; Muller, N.; Botes, W.; Fox, G.; Manley, M. A review of triticale uses and the effect of growth environment on grain quality. *J. Sci. Food Agric.* **2011**, *91*, 1155–1165. [CrossRef]
28. Hermes, J.C.; Johnson, R.C. Effects of feeding various levels of triticale var. Bogo in the diet of broiler and layer chickens. *J. Appl. Poult. Res.* **2004**, *13*, 667–672. [CrossRef]
29. Djekic, V.; Pandurevic, T.; Mitrovic, S.; Radovic, V.; Milivojevic, J.; Djermanovic, V. Nutritional Value of Triticale (Trijumf) for Broiler Diets. In Proceedings of the Third International Scientific Symposium "Agrosym Jahorina 2012", Jahorina, Bosnia and Herzegovina, 15–17 November 2012; pp. 15–17. Available online: https://www.cabidigitallibrary.org/doi/pdf/10.5555/20143100079 (accessed on 9 February 2024).
30. Lim, C.; Poaty Ditengou, J.; Ryu, K.; Ku, J.; Park, M.; Whiting, I.M.; Pirgozliev, V. Effect of replacing maize with different levels of triticale on laying hen performance, egg quality, yolk fatty acid profile and blood options. *J. Anim. Feed Sci.* **2021**, *30*, 360–366. [CrossRef]
31. Osek, M.; Milczarek, A.; Janocha, A.; Świnarska, R. Effect of triticale as a partial or complete wheat and maize substitute in broiler chicken diets on growth performance, slaughter value and meat quality. *Ann. Anim. Sci.* **2010**, *10*, 275–283. Available online: https://www.cabidigitallibrary.org/doi/full/10.5555/20113025674 (accessed on 10 February 2024).
32. Gradziuk, P.; Jończyk, K.; Gradziuk, B.; Wojciechowska, A.; Trocewicz, A.; Wysokiński, M. An economic assessment of the impact on agriculture of the proposed changes in EU biofuel policy mechanisms. *Energies* **2021**, *14*, 6982. [CrossRef]
33. Liu, X.; Unaegbunam, E.; Stuart, D.T. Co-production of isobutanol and ethanol from prairie grain starch using engineered *Saccharomyces cerevisiae*. *Fermentation* **2021**, *7*, 150. [CrossRef]
34. Wilczyński, D.; Talaśka, K.; Wałęsa, K.; Wojtkowiak, D.; Bembenek, M. Experimental study on the cutting process of single triticale straws. *Materials* **2023**, *16*, 3943. [CrossRef]
35. Obidziński, S.; Cwalina, P.; Kowczyk-Sadowy, M.; Krasowska, M.; Sienkiewicz, A.; Faszczewski, D.; Szyszlak-Bargłowicz, J. The use of bread bakery waste as a binder additive in the production of fuel pellets from straw. *Energies* **2023**, *16*, 7313. [CrossRef]
36. Silkova, O.G.; Ivanova, Y.N.; Loginova, D.B.; Solovey, L.A.; Sycheva, E.A.; Dubovets, N.I. Karyotype reorganization in wheat–rye hybrids obtained via unreduced gametes: Is there a limit to the chromosome number in triticale? *Plants* **2021**, *10*, 2052. [CrossRef]
37. Zhu, F. Triticale: Nutritional composition and food uses. *Food Chem.* **2018**, *241*, 468–479. [CrossRef]
38. Gołębiowska, G.; Dyda, M.; Wajdzik, K. Quantitative trait loci and candidate genes associated with cold-acclimation and *Microdochium nivale* tolerance/susceptibility in winter triticale (x *Triticosecale*). *Plants* **2021**, *10*, 2678. [CrossRef]
39. Golebiowska-Paluch, G.; Dyda, M. The genome regions associated with abiotic and biotic stress tolerance, as well as other important breeding traits in triticale. *Plants* **2023**, *12*, 619. [CrossRef]
40. Nielsen, D.C.; Lyon, D.J.; Miceli-Garcia, J.J. Replacing fallow with forage triticale in a dryland wheat-corn-fallow rotation may increase profitability. *Field Crops Res.* **2017**, *203*, 227–237. [CrossRef]
41. Faccini, N.; Morcia, C.; Terzi, V.; Rizza, F.; Badeck, F.-W. Triticale in Italy. *Biology* **2023**, *12*, 1308. [CrossRef]
42. Erickson, J.P. Triticale—A review of its nutritional value. *Millg. Feed Fertil.* **1984**, *167*, 13–15.

43. Al-Athari, A.K.; Guenter, W. Nutritional value of triticale (Carman) for broiler diets. *Anim. Feed Sci. Technol.* **1988**, *22*, 119–130. [CrossRef]
44. Flores, M.P.; Castaño, J.I.R.; McNab, J.M. Effect of enzyme supplementation of wheat and triticale based diets for broilers. *Anim. Feed Sci. Technol.* **1994**, *49*, 237–243. [CrossRef]
45. Dziki, D.; Hassoon, W.H.; Kramek, A.; Krajewska, A. Grinding characteristics of new varieties of winter triticale grain. *Processes* **2023**, *11*, 1477. [CrossRef]
46. Samtiya, M.; Aluko, R.E.; Dhewa, T. Plant food anti-nutritional factors and their reduction strategies: An overview. *Food Prod. Process. Nutr.* **2020**, *2*, 6. [CrossRef]
47. Al-Athari, A.K.; Guenter, W. The effect of fat level and type on the utilization of triticale (cultivar Carman) by broiler chicks. *Anim. Feed Sci. Technol.* **1989**, *22*, 273–284. [CrossRef]
48. Emtseva, M.V. The use of *Vrn* genes for creation of triticale forms with different length of vegetation period. *Sel'skokhozyaistvennaya Biol. Agric. Biol.* **2019**, *55*, 3–14. [CrossRef]
49. Wójcik-Gront, E.; Studnicki, M. Long-term yield variability of triticale (×*Triticosecale* Wittmack) tested using a CART model. *Agriculture* **2021**, *11*, 92. [CrossRef]
50. Miedaner, T.; Flath, K.; Starck, N.; Weißmann, S.; Maurer, H.P. Quantitative-genetic evaluation of resistances to five fungal diseases in a large triticale diversity panel (×*Triticosecale*). *Crops* **2022**, *2*, 218–232. [CrossRef]
51. Voloshchuk, S.I.; Kyslyh, T.M.; Voloshchuk, G.D. Toxigenicity of Fungi of the Genus Fusarium Link on Winter Triticale. In *Scientific Support for the Production of Triticale Grain and Its Processing Products, Abstracts of Reports of the Scientific Practical Conference, Kharkiv, Ukraine, 6–8 July 2005*; V.Ya. Yuriev Institute of Plant Production: Kharkiv, Ukraine, 2005; pp. 5–6. (In Ukrainian)
52. Góral, T.; Wiśniewska, H.; Ochodzki, P.; Twardawska, A.; Walentyn-Góral, D. Resistance to fusarium head blight, kernel damage, and concentration of *Fusarium* mycotoxins in grain of winter triticale (x *Triticosecale* Wittmack) lines. *Agronomy* **2021**, *11*, 16. [CrossRef]
53. Góral, T.; Wiśniewska, H.; Ochodzki, P.; Walentyn-Góral, D. Higher *Fusarium* toxin accumulation in grain of winter triticale lines inoculated with *Fusarium culmorum* as compared with wheat. *Toxins* **2016**, *8*, 301. [CrossRef]
54. Kwiatek, M.T.; Noweiska, A.; Bobrowska, R.; Czapiewska, A.; Aygün, M.; Munyamahoro, F.d.; Mikołajczyk, S.; Tomkowiak, A.; Kurasiak-Popowska, D.; Poślednik, P. Novel tetraploid triticale (einkorn wheat × Rye)—A source of stem rust resistance. *Plants* **2023**, *12*, 278. [CrossRef]
55. Zhang, J.; Wellings, C.R.; McIntosh, R.A.; Park, R.F. Seedling resistances to rust diseases in international triticale germplasm. *Crop. Pasture Sci.* **2010**, *61*, 1036–1048. [CrossRef]
56. Kurkiev, U.K.; Kurkiev, K.U. Triticale Resistance to Yellow Rust. In *Scientific Support for the Production of Triticale Grain and Its Processing Products, Abstracts of Reports of the Scientific Practical Conference, Kharkiv, Ukraine, 6–8 July 2005*; V.Ya. Yuriev Institute of Plant Production: Kharkiv, Ukraine, 2005; pp. 3–15. (In Ukrainian)
57. Kolesnikov, L.E.; Vlasova, E.A.; Funtikova, E.Y.; Kolesnikova, Y.R. Triticale resistance to the main phytopathogenic organisms of Northwest region of the Russian Federation. *Sel'skokhozyaistvennaya Biol. Agric. Biol.* **2013**, *3*, 110–116. Available online: http://www.agrobiology.ru/articles/3-2013kolesnikov.pdf (accessed on 6 January 2024). [CrossRef]
58. Zhao, F.; Niu, K.; Tian, X.; Du, W. Triticale improvement: Mining of genes related to yellow rust resistance in triticale based on transcriptome sequencing. *Front. Plant Sci.* **2022**, *13*, 883147. [CrossRef]
59. Ledesma-Ramírez, L.; Solis-Moya, E.; Ramírez-Pimentel, J.G.; Dreisigacker, S.; Huerta-Espino, J.; Aguirre-Mancilla, C.L.; Mariscal-Amaro, L.A. Relationship between the number of partial resistance genes and the response to leaf rust in wheat genotypes. *Chil. J. Agric. Res.* **2018**, *78*, 400–408. [CrossRef]
60. Kapustina, T.B. Hybrid Lines of Spring Triticale as Starting Material for Breeding. In *Scientific Support for the Production of Triticale Grain and Its Processing Products, Abstracts of Reports of the Scientific Practical Conference, Kharkiv, Ukraine, 6–8 July 2005*; V.Ya. Yuriev Institute of Plant Production: Kharkiv, Ukraine, 2005; pp. 16–17. (In Ukrainian)
61. Khmara, V.V.; Gruzinov, S.K. The Influence of Sowing Dates on the Productivity of Winter and Spring Triticale. In *Scientific Support for the Production of Triticale Grain and Its Processing Products, Abstracts of Reports of the Scientific Practical Conference, Kharkiv, Ukraine, 6–8 July 2005*; V.Ya. Yuriev Institute of Plant Production: Kharkiv, Ukraine, 2005; p. 67. (In Ukrainian)
62. Ryabchun, V.K.; Shatokhin, V.I.; Lisnychiy, V.A.; Kapustina, T.B. *Spring Triticale for Stable Grain Production*; Institute of Plant Breeding Named after V.Ya. Yuryev, UAAS: Kharkiv, Ukraine, 2007. (In Ukrainian)
63. Smulska, I.V.; Khomenko, T.M. Replenishment of the Ukrainian Plant Varieties Market: Winter and Spring Tritical. In *Triticale—Culture of the 21st Century, Abstracts of Reports of the International Scientific and Practical Conference, Kharkiv, Ukraine, 4–6 July 2017*; V.Ya. Yuriev Institute of Plant Production: NAAS: Kharkiv, Ukraine, 2017; pp. 47–48. (In Ukrainian)
64. Randhawa, H.S.; Bona, L.; Graf, R.J. Triticale breeding—Progress and prospect. In *Triticale*; Eudes, F., Ed.; Springer: Cham, Switzerland, 2015; pp. 15–32. [CrossRef]
65. Royo, C.; Insa, J.A.; Boujenna, A.; Ramos, J.M.; Montesinos, E. Yield and quality of spring triticale used for forage and grain as influenced by sowing date and cutting stage. *Field Crops Res.* **1994**, *37*, 161–168. [CrossRef]
66. Gamayunova, V.V.; Sydiakina, O.V.; Dvoretskyi, V.F.; Markovska, O.Y. Productivity of spring triticale under conditions of the southern steppe of Ukraine. *Ecol. Eng. Environ. Technol.* **2021**, *22*, 104–112. [CrossRef] [PubMed]
67. Zakharchuk, O.; Hutorov, A.; Vyshnevetska, O.; Nitsenko, V.; Balezentis, T.; Streimikiene, D. Ukraine's market of certified seed: Current state and prospects for the future. *Agriculture* **2023**, *13*, 61. [CrossRef]

68. Solovyov, O.; Zholaman, R.; Shvidchenko, V. Influence of sowing dates and seeding rates of spring triticale (Triticosecale Wittmack) on yields and crop structure elements. *Int. J. Des. Nat. Ecodyn.* **2023**, *18*, 207–212. [CrossRef]
69. Salmon, D.; Temelli, F.; Spence, S. Chemical Composition of Western Canadian Triticale Varieties. In Proceedings of the 5th International Triticale Symposium, Radzików, Poland, 30 June–5 July 2002; Plant Breeding and Acclimatization Institute: Radzików, Poland, 2002; Volume II, pp. 445–450. Available online: https://www.cabidigitallibrary.org/doi/pdf/10.5555/20123099142 (accessed on 10 February 2024).
70. Avramenko, S.M. Yield of Spring Triticale and Wheat on Different Backgrounds of Mineral Nutrition. In *Scientific Support for the Production of Triticale Grain and Its Processing Products, Abstracts of Reports of the Scientific Practical Conference, Kharkiv, Ukraine, 6–8 July 2005*; V.Ya. Yuriev Institute of Plant Production: Kharkiv, Ukraine, 2005; pp. 55–56. (In Ukrainian)
71. Hrebenyuk, I.V.; Shatokhin, V.I.; Ryabchun, V.K. Breeding innovations—Varieties of spring triticale. *Vìsnik Cent. Nauk. Zabezpečennâ APV Harkìvs′koï Obl. Bull. Cent. Sci. Provis. Agroind. Kharkov Reg.* **2006**, *6*, 65–69. (In Ukrainian)
72. Wojtkowiak, K.; Stępień, A.; Warechowska, M.; Konopka, I.; Klasa, A. Effect of fertilisation technique on some indices of nutritional value of spring triticale grain. *J. Elem.* **2014**, *19*, 229–242. [CrossRef]
73. Guedes-Pinto, H.; Darvey, N.; Carnide, V.P. (Eds.) Triticale: Today and Tomorrow. In *Developments in Plant Breeding*; Kluwer Academic Publishers, Springer Science & Business Media: Dordrecht, The Netherlands, 2012; Volume 5.
74. Bielski, S.; Dubis, B.; Budzyński, W. Influence of nitrogen fertilisation on the technological value of semi-dwarf grain winter triticale varieties Alekto and Gniewko. *Pol. J. Nat. Sci.* **2015**, *30*, 325–336. Available online: http://www.uwm.edu.pl/polish-journal/sites/default/files/issues/articles/bielski_2015.pdf (accessed on 10 February 2024).
75. Gerdzhikova, M.; Grozeva, N.; Pavlov, D.; Tzanova, M. Effect of nitrogen fertilization in *Triticale* (× *Triticosecale* Wittm.), cultivated after different predecessors. Nitrogen uptake and efficiency. *AGROFOR Int. J.* **2017**, *2*, 147–156. [CrossRef]
76. Ayalew, H.; Kumssa, T.T.; Butler, T.J.; Ma, X.F. Triticale improvement for forage and cover crop uses in the southern great plains of the United States. *Front. Plant Sci.* **2018**, *9*, 1130–1136. [CrossRef]
77. Bratyshko, N.I.; Ryabchun, V.K.; Hrytsenko, R.B.; Gaviley, O.V. The fodder value of triticale of different varieties depends on the growing season. *Vìsnik Cent. Nauk. Zabezpečennâ APV Harkìvs′koï Obl. Bull. Cent. Sci. Provis. Agroind. Kharkov Reg.* **2009**, *6*, 29–36. (In Ukrainian)
78. Niedziela, A.; Domżalska, L.; Dynkowska, W.M.; Pernisová, M.; Rybka, K. Aluminum stress induces irreversible proteomic changes in the roots of the sensitive but not the tolerant genotype of triticale seedlings. *Plants* **2022**, *11*, 165. [CrossRef] [PubMed]
79. Baron, V.S.; Juskiw, P.E.; Aljarrah, M. Triticale as a Forage. In *Triticale*; Eudes, F., Ed.; Springer: Cham, Switzerland, 2015; pp. 189–212. [CrossRef]
80. De Zutter, A.; Landschoot, S.; Vermeir, P.; Van Waes, C.; Muylle, H.; Roldán-Ruiz, I.; Douidah, L.; De Boever, J.; Haesaert, G. Variation in potential feeding value of triticale forage among plant fraction, maturity stage, growing season and genotype. *Heliyon* **2023**, *9*, e12760. [CrossRef] [PubMed]
81. Ryabchun, V.K. The Role of Triticale in the Diversification and Stabilization of the Production of Grain and Its Processing Products. In *Scientific Support for the Production of Triticale Grain and Its Processing Products, Abstracts of Reports of the Scientific Practical Conference, Kharkiv, Ukraine, 6–8 July 2005*; V.Ya. Yuriev Institute of Plant Production: Kharkiv, Ukraine, 2005; pp. 3–4. (In Ukrainian)
82. Jańczak-Pieniążek, M. The influence of cropping systems on photosynthesis, yield, and grain quality of selected winter triticale cultivars. *Sustainability* **2023**, *15*, 11075. [CrossRef]
83. Coblentz, W.K.; Akins, M.S.; Kalscheur, K.F.; Brink, G.E.; Cavadini, J.S. Effects of growth stage and growing degree day accumulations on triticale forages: 1. Dry matter yield, nutritive value, and in vitro dry matter disappearance. *J. Dairy Sci.* **2018**, *101*, 8965–8985. [CrossRef]
84. Grabovets, A.I.; Shevchenko, N.A. The Use of Triticale in the Production of Bread and Cookies. In *Scientific Support for the Production of Triticale Grain and Its Processing Products, Abstracts of Reports of the Scientific Practical Conference, Kharkiv, Ukraine, 6–8 July 2005*; V.Ya. Yuriev Institute of Plant Production: Kharkiv, Ukraine, 2005; p. 37. (In Ukrainian)
85. Leon, A.E.; Rubiolo, A.; Anon, M.C. Use of triticale flours in cookies: Quality factors. *Cereal Chem.* **1996**, *73*, 779–784. Available online: https://www.cerealsgrains.org/publications/cc/backissues/1996/Documents/73_779.pdf (accessed on 9 February 2024).
86. Babich, Y.V.; Solodushko, M.M.; Pikhtin, M.I.; Gromov, M.I. Cultivation Features, Yield and Grain Quality of Winter Triticale. In *Scientific Support for the Production of Triticale Grain and Its Processing Products, Abstracts of Reports of the Scientific Practical Conference, Kharkiv, Ukraine, 6–8 July 2005*; V.Ya. Yuriev Institute of Plant Production: Kharkiv, Ukraine, 2005; pp. 56–57. (In Ukrainian)
87. Lalević, D.; Biberdžić, M.; Jelić, M.; Barać, S. The characteristics of triticale cultivated in rural areas. *Poljopr. Šumar. Agric. For.* **2012**, *58*, 27–34. Available online: http://89.188.43.75/agricultforest/20130314-03%20Lalevic%20et%20al.pdf (accessed on 9 February 2024).
88. De Lange, L.; Rombouts, C.; Elferink, G.O. Practical application and advantages of using total digestible amino acids and undigestible crude protein to formulate broiler diets. *Worlds Poult. Sci. J.* **2003**, *59*, 447–457. [CrossRef]
89. National Research Council. *Nutrient Requirements of Swine*, 11th ed.; National Research Council of the National Academies, The National Academies Press: Washington, DC, USA, 2012; ISBN 0309224233. Available online: https://nap.nationalacademies.org/catalog/13298/nutrient-requirements-of-swine-eleventh-revised-edition (accessed on 20 November 2023).

90. Nuriev, G.G.; Borovik, E.S. Results of studies on replacing wheat with triticale grain in the diet of broiler chickens. *Vestn. Brânskoj GSHA Vestn. Bryansk State Agric. Acad.* **2012**, *6*, 20–24. Available online: https://www.bgsha.com/download/education/library/vestnik/vestnik-6-2012.pdf (accessed on 20 November 2023). (In Russian)
91. Korver, D.R.; Zuidhof, M.J.; Lawes, K.R. Performance characteristics and economic comparison of broiler chickens fed wheat-and triticale-based diets. *Poult. Sci.* **2004**, *83*, 716–725. [CrossRef]
92. Elangovan, A.V.; Bhuiyan, M.; Jessop, R.; Iji, P.A. The potential of high-yielding triticale varieties in the diet of broiler chickens. *Asian J. Poult. Sci.* **2011**, *5*, 68–76. [CrossRef]
93. Bratishko, N.I.; Gaviley, E.V.; Gritsenko, R.B.; Ryabchun, V.K.; Pritulenko, O.V. Comparative assessment of the feeding qualities of different triticale varieties. *Ptahìvnictvo Poult. Farming* **2007**, *59*, 43–48. (In Russian)
94. Klassen, A.J.; Hill, R.D. Comparison of starch from triticale and its parental species. *Cereal Chem.* **1971**, *48*, 647–654. Available online: https://www.cerealsgrains.org/publications/cc/backissues/1971/Documents/chem48_647.pdf (accessed on 20 November 2023).
95. Aaman, P.; Hesselman, K. Analysis of starch and other main constituents of cereal grains. *Swed. J. Agric. Res.* **1984**, *14*, 135–139. Available online: https://agris.fao.org/search/en/records/6471ba8c77fd37171a6d7ad1 (accessed on 20 November 2023).
96. Flores, M.P.; Castañon, J.I.R.; McNab, J.M. Nutritive value of triticale fed to cockerels and chicks. *Br. Poult. Sci.* **1994**, *35*, 527–536. [CrossRef] [PubMed]
97. Agrawal, P.K. Changes in amylase, starch and reducing sugars during grain development in triticale and their relation to grain shrivelling. *Cereal Res. Commun.* **1977**, *5*, 225–233. Available online: https://www.jstor.org/stable/23778562 (accessed on 20 November 2023).
98. Auelbek, A.; Aimenova, Z.; Abai, G.; Usenova, U.; Daulbaj, A. Physical and chemical properties of triticale grain. *Internauka* **2019**, *3*, 6–8. Available online: https://staff.tiiame.uz/storage/users/422/articles/BwdwmAiPNIF6MLFMT2jU2zfRilANvy7t9otr9zOL.pdf (accessed on 5 January 2024).
99. Harinder, K.; Bains, G.S. Studies on baking of high alpha-amylase flours: Effect of pH, salt and L-cysteine ± HCI in the dough. *Food/Nahrung* **1988**, *32*, 481–490. [CrossRef]
100. Piazza, I.; Carnevali, P.; Faccini, N.; Baronchelli, M.; Terzi, V.; Morcia, C.; Ghizzoni, R.; Patrone, V.; Morelli, L.; Cervini, M.; et al. Combining native and malted triticale flours in biscuits: Nutritional and technological implications. *Foods* **2023**, *12*, 3418. [CrossRef]
101. Ciesarová, Z.; Kukurová, K.; Jelemenská, V.; Horváthová, J.; Kubincová, J.; Belović, M.; Torbica, A. Asparaginase treatment of sea buckthorn berries as an effective tool for acrylamide reduction in nutritionally enriched wholegrain wheat, rye and triticale biscuits. *Foods* **2023**, *12*, 3170. [CrossRef]
102. Rakha, A.; Åman, P.; Andersson, R. Dietary fiber in triticale grain: Variation in content, composition, and molecular weight distribution of extractable components. *J. Cereal Sci.* **2011**, *54*, 324–331. [CrossRef]
103. Chen, C.H.; Bushuk, W. Nature of proteins in *Triticale* and its parental species: I. Solubility characteristics and amino acid composition of endosperm proteins. *Can. J. Plant Sci.* **1970**, *50*, 9–14. [CrossRef]
104. Borysenko, V.G.; Yastrebov, K.Y.; Ionov, I.A. Amino acid nutrition. *Sučasne Ptahìvnictvo Mod. Poult. Farming* **2004**, *10*, 9. (In Ukrainian)
105. Myer, R.O.; Brendemuhl, J.H.; Barnett, R.D. Crystalline lysine and threonine supplementation of soft red winter wheat or triticale, low-protein diets for growing-finishing swine. *J. Anim. Sci.* **1996**, *74*, 577–583. [CrossRef]
106. Otchenashko, V.V. Nutrient utilization in young quails fed compound feeds with different protein levels. *Nauk. Dopovìdì Nacìonal′nogo Unìversitetu Bìoresursìv Ì Prir. Ukraïni Sci. Rep. NULES Ukr.* **2012**, *8*, 38–40. (In Ukrainian)
107. Bakhtiyary Moez, N.; Mirzaie Goudarzi, S.; Saki, A.A.; Ahmadi, A. Effect of ground or whole wheat and triticale on productive performance, egg quality, gastrointestinal tract traits and nutrient digestibility of laying Japanese quails. *Iran. J. Appl. Anim.Sci.* **2020**, *10*, 355–363. Available online: https://ijas.rasht.iau.ir/article_673255_5df8021198a6d3822bfc7d81e626735d.pdf (accessed on 10 February 2024).
108. Tarkowski, C.; Tochman, L.; Kimsa, E. Zmienność zawartości białka i lizyny w ziarniakach Triticale Variability of protein and lysine content in Triticale grains. *Hod. Rośl. Aklim. Nasien. Plant Breed. Seed Acclim.* **1974**, *18*, 351–358. (In Polish)
109. Ruckman, J.E.; Zscheile, F.P., Jr.; Qualset, C.O. Protein, lysine, and grain yields of triticale and wheat as influenced by genotype and location. *J. Agric. Food Chem.* **1973**, *21*, 697–700. [CrossRef]
110. Villegas, E.; McDonald, C.E.; Gilles, K.A. Variability in the lysine content of wheat rye and Triticale proteins. *Cereal Chem.* **1970**, *47*, 746–757. Available online: https://www.cerealsgrains.org/publications/cc/backissues/1970/Documents/CC1970a96.html (accessed on 20 November 2023).
111. Hraska, S. Heritabilita aminokyselin Triticale Heritability of Triticale amino acids. *Pol′nohospodárstvo Agric.* **1975**, *21*, 295–300. (In Slovak)
112. Podobed, L.I. Triticale, Soriz, Chumiza—Promising Grain Components of Compound Feed. 2008–2020. Available online: https://web.archive.org/web/20200222104041/http://podobed.org/tritikale_soriz_chumiza_-_perspektivnye_zernovye_komponenty_kombikorma.html (accessed on 20 November 2023). (In Russian)
113. Kaszuba, J.; Kapusta, I.; Posadzka, Z. Content of phenolic acids in the grain of selected Polish triticale cultivars and its products. *Molecules* **2021**, *26*, 562. [CrossRef]

114. Jańczak-Pieniążek, M.; Horvat, D.; Viljevac Vuletić, M.; Kovačević Babić, M.; Buczek, J.; Szpunar-Krok, E. Antioxidant potential and phenolic acid profiles in triticale grain under integrated and conventional cropping systems. *Agriculture* **2023**, *13*, 1078. [CrossRef]
115. Jonnala, R.S.; Irmak, S.; MacRitchie, F.; Bean, S.R. Phenolics in the bran of waxy wheat and triticale lines. *J. Cereal Sci.* **2010**, *52*, 509–515. [CrossRef]
116. Landfried, K.E. Die Eignung von Triticale als Futter für Geflügel The suitability of Triticale as feed for poultry. *Osterr. Geflugelwirtsch. Austrian Poult. Farming* **1989**, *28*, 310–314. (In German)
117. Wilson, B.J.; McNab, J.M. The nutritive value of triticale and rye in broiler diets containing field beans (*Vicia faba* L.). *Br. Poult. Sci.* **1975**, *16*, 17–22. [CrossRef]
118. Bratyshko, N.I.; Ionov, I.A.; Ibatullin, I.I.; Prytulenko, O.V. Effective Feeding of Farm Poultry. Ahrarna Nauka: Kyiv, Ukraine, 2013. (In Ukrainian)
119. Thirumalaisamy, G.; Muralidharan, J.; Senthilkumar, S.; Hema Sayee, R.; Priyadharsini, M. Cost-effective feeding of poultry. *Int. J. Environ. Sci. Technol.* **2016**, *5*, 3997–4005.
120. Bilitiuk, A.P. Valuable fodder for livestock. *Kormi ì kormovirobnictvo Feeds Feed Prod.* **2005**, *55*, 114–120. Available online: http://base.dnsgb.com.ua/files/journal/Kormy-i-kormovyrobnycstvo/KiK2005-55/KiK2005-55_114-120.pdf (accessed on 20 November 2023). (In Ukrainian)
121. Purwin, C.; Opyd, P.M.; Baranowska, M.; Borsuk-Stanulewicz, M. The effect of diets containing high-moisture corn or triticale grain on animal performance and the fatty acid composition of lamb muscles. *Animals* **2022**, *12*, 3130. [CrossRef] [PubMed]
122. Çiftçi, I.; Yenise, E.; Eleroğlu, H. Use of triticale alone and in combination with wheat or maize: Effects of diet type and enzyme supplementation on hen performance, egg quality, organ weights, intestinal viscosity and digestive system characteristics. *Anim. Feed Sci. Technol.* **2003**, *105*, 149–161. [CrossRef]
123. Gulic, A.F. The use of triticale in the diets of young goslings. *Naučn. ž. Kuban. gos. agrar. univ. Sci. J. KubSAU* **2014**, *100*, 892–907. Available online: http://ej.kubagro.ru/2014/06/pdf/76.pdf (accessed on 20 November 2023). (In Russian)
124. Bratyshko, N.I.; Prytulenko, O.V.; Gaviley, O.V.; Polyakova, L.L.; Hrytsenko, R.B. Triticale in Poultry Feed: Methodical Recommendations. Poultry Research Institute: Birky, Ukraine, 2010. (In Ukrainian)
125. Bratishko, N.I.; Gaviley, E.V.; Pritulenko, O.V.; Tereshchenko, A.V. Triticale in feeding meat-egg chickens. *Pticevodstvo Poult. Farming* **2012**, *4*, 41–43. Available online: https://www.elibrary.ru/item.asp?id=17668326 (accessed on 20 November 2023). (In Russian).
126. Gaviley, O.V.; Katerynych, O.O. Technological methods of optimizing the feeding of parent flock chickens using non-traditional grain crops. *Sučasne ptahìvnictvo Modern Poult. Farming* **2016**, *11–12*, 24–26. (In Ukrainian)
127. Maurice, D.V.; Jones, J.E.; Lightsey, S.F.; Rhoades, J.F.; Hsu, K.T. Chemical composition and nutritive value of triticale (Florida 201) for broiler chickens. *Appl. Agric. Res.* **1989**, *4*, 243–247. Available online: https://agris.fao.org/search/en/providers/122535/records/64775447bc45d9ecdbc13537 (accessed on 15 January 2024).
128. Brzóska, F. Pszenżyto w żywieniu zwierząt Triticale in animal nutrition. *Prz. Hod.* **1986**, *54*, 18–20. (In Polish)
129. Pettersson, D. Substitution of maize with different levels of wheat, triticale or rye in diets for broiler chickens. *Swed. J. Agric. Res.* **1987**, *17*, 57–62. Available online: https://agris.fao.org/search/en/records/6471c0a877fd37171a6e8ec1 (accessed on 20 November 2023).
130. Charalambous, K.; Koumas, A.; Economides, S. The effect of triticale grain on the performance of chicks from birth to nine weeks of age. *Tech. Bull. Agric. Res. Inst.* **1986**, *79*, 1–7. Available online: http://publications.ari.gov.cy/tb/1986/Technical%20Bulletin%2079%20full%20text,%201986.pdf (accessed on 20 November 2023).
131. Leeson, S.; Summers, J.D. Response of White Leghorns to diets containing ground or whole triticale. *Can. J. Anim. Sci.* **1987**, *67*, 583–585. [CrossRef]
132. Proudfoot, F.G.; Hulan, H.W. Nutritive value of triticale as a feed ingredient for broiler chickens. *Poult. Sci.* **1988**, *67*, 1743–1749. [CrossRef]
133. Bratyshko, N.I.; Prytulenko, O.V.; Haviley, O.V. Peculiarities of the effect of winter and spring triticale on metabolism in the chicken's organism. *Bìol. Tvarin Anim. Biol.* **2008**, *10*, 196–201. Available online: http://archive.inenbiol.com.ua:8080/bt/2008/3/3.pdf (accessed on 15 January 2024). (In Ukrainian)
134. Shafey, T.M.; Dingle, J.G.; McDonald, M.W. Comparison between wheat, triticale, rye, soyabean oil and strain of laying bird on the production, and cholesterol and fatty acid contents of eggs. *Br. Poult. Sci.* **1992**, *33*, 339–346. [CrossRef]
135. Bratyshko, N.I.; Polyakova, L.L.; Prytulenko, O.V.; Tereshchenko, O.V.; Gaviley, O.V. The effect of an increased level of individual amino acids in compound feed with triticale on the metabolism in the body of chickens. *Ptahìvnictvo Poult. Farming* **2011**, *67*, 37–43. Available online: https://www.researchgate.net/publication/342816297_Bratisko_NI_Polakova_LL_Pritulenko_OV_Teresenko_OV_Gavilej_OV_Vpliv_pidvisenogo_rivna_okremih_aminokislot_v_kombikormah_z_tritikale_na_obmin_recovin_v_organizmi_kurej_Ptahivnictvo_mizvid_temat_nauk_zb (accessed on 20 November 2023). (In Ukrainian)
136. Hrytsenko, R.B.; Prytulenko, O.V.; Tereshchenko, O.V.; Gaviley, O.V. Economic efficiency of using triticale extrudates in feeding poultry breeders. *Ptahìvnictvo Poult. Farming* **2009**, *63*, 54–61. Available online: https://www.researchgate.net/publication/342883188_Gricenko_RB_Pritulenko_OV_Teresenko_OV_Gavilej_OV_Ekonomicna_efektivnist_vikoristanna_ekstrudativ_tritikale_v_godivli_pleminnoi_ptici_Ptahivnictvo_-_2009_-_Vip_63_-_S_54-61 (accessed on 20 November 2023). (In Ukrainian)

137. Savage, T.F.; Holmes, Z.A.; Nilipour, A.H.; Nakaue, H.S. Evaluation of cooked breast meat from male breeder turkeys fed diets containing varying amounts of triticale, variety Flora. *Poult. Sci.* **1987**, *66*, 450–452. [CrossRef]
138. Lagodyuk, P.; Slabitskyi, Y.; Ratych, I.; Kyryliv, Y. *Synthetic Amino Acids and Sulfur—Stimulators of Animal and Poultry Productivity: Methodical Recommendations*; Lviv, Ukraine, 1987. (In Ukrainian)
139. Svezhentsov, A.I.; Urdzik, R.M.; Egorov, I.A. *Feed and Feeding of Poultry*; Art Press: Dnepropetrovsk, Ukraine, 2006. (In Russian)
140. Alagawany, M.; El-Hindawy, M.M.; Ali, A.A.; Soliman, M.M. Protein and total sulfur amino acids relationship effect on performance and some blood parameters of laying hens. *Egypt. J. Nutr. Feeds* **2011**, *14*, 477–487. Available online: https://www.researchgate.net/profile/Mahmoud-Alagawany/publication/258763293_Protein_and_Total_Sulfur_Amino_Acids_Relationship_Effect_on_Performance_and_Some_Blood_Parameters_of_Laying_Hens/links/00b7d528e824de5610000000/Protein-and-Total-Sulfur-Amino-Acids-Relationship-Effect-on-Performance-and-Some-Blood-Parameters-of-Laying-Hens.pdf (accessed on 10 February 2024).
141. Podobed, L.I. Comparative effectiveness of lysine feed preparations in mixed feed for farm animals and poultry. *Efektyvne tvarynnytstvo Efficient Anim. Husb.* **2006**, *7*, 22–27. (In Russian)
142. Manni, K.; Lötjönen, T.; Huuskonen, A. Comparing spring triticale varieties to barley and wheat varieties when harvested as whole crop. *Agric. Food Sci.* **2021**, *30*, 24–35. [CrossRef]
143. Waldman, A.R.; Surai, P.F.; Ionov, I.A.; Sakhatsky, N.I. *Vitamins in Animal Nutrition (Metabolism and Requirements)*; RIP "Original": Kharkov, Ukraine, 1993. (In Russian)
144. Bratyshko, N.I.; Gaviley, O.V.; Tereshchenko, O.V.; Prytulenko, O.V. The effect of triticale on the vitamin content of eggs of chickens of different breeds. *Hran. I Pererab. Zerna Storage Process. Grain* **2010**, *10*, 59–62. Available online: https://www.researchgate.net/publication/342788400_Bratisko_NI_Gavilej_OV_Teresenko_OV_Pritulenko_OV_Vpliv_tritikale_na_vitaminnu_zabezpecenist_aec_kurej_riznih_porid_Hranenie_i_pererabotka_zerna_ezemes_nauc-prakt_zurn_ucreditel_OOO_APK-Zerno_-_D_Art-?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InByb2ZpbGUiLCJwYWdlIjoic2VhcmNoIiwicG9zaXRpb24iOiJwYWdlSGVhZGVyIn19 (accessed on 20 November 2023). (In Ukrainian)
145. Bratyshko, N.I.; Gaviley, O.V.; Tereshchenko, O.V.; Prytulenko, O.V. The effect of triticale on the vitamin content of eggs of chickens of different breeds. *Ptahìvnictvo Poult. Farming* **2010**, *65*, 93–100. Available online: http://avianua.com/archiv/ptahivnictvo/65/10.pdf (accessed on 20 November 2023). (In Ukrainian)
146. D'Mello, J.P.F. Amino acid supplementation of cereal-based diets for non-ruminants. *Anim. Feed Sci. Technol.* **1993**, *45*, 1–18. [CrossRef]
147. Diependaete, J. Aliment flocon: Digestion facile, lactation tranguelle Cereal food: Easy digestion, easy lactation. *Agrusert* **1985**, *1051*, 27. (In French)
148. Shimada, A.; Cline, T.R. Limiting amino acids of triticale for the growing rat and pig. *J. Anim. Sci.* **1974**, *38*, 941–946. [CrossRef]
149. Scholtyssek, S.; Kutritz, B. Improvement of broiler rations with domestic polish feed components, 3: Triticale in combination with other grains in broiler rations. *Arch. Geflugelk.* **1986**, *50*, 140–143. Available online: https://agris.fao.org/search/en/providers/122438/records/647750d8a3fd11e4303902bd (accessed on 20 November 2023).
150. Nadeem, M.; Anjum, F.M.; Amir, R.M.; Khan, M.R.; Hussain, S.; Javed, M.S. An overview of anti-nutritional factors in cereal grains with special reference to wheat—A review. *Pak. J. Food Sci.* **2010**, *20*, 54–61. Available online: https://www.researchgate.net/publication/233816063_An_overview_of_anti-nutritional_factors_in_cereal_grains_with_special_reference_to_wheat-A_review (accessed on 20 November 2023).
151. Jaroni, D.I.V.Y.A.; Scheideler, S.E.; Beck, M.; Wyatt, C. The effect of dietary wheat middlings and enzyme supplementation. 1. Late egg production efficiency, egg yields, and egg composition in two strains of Leghorn hens. *Poult. Sci.* **1999**, *78*, 841–847. [CrossRef] [PubMed]
152. Coppedge, J.R.; Oden, L.A.; Ratliff, B.; Brown, B.; Ruch, F.; Lee, J.T. Evaluation of nonstarch polysaccharide-degrading enzymes in broiler diets varying in nutrient and energy levels as measured by broiler performance and processing parameters. *J. Appl. Poult. Res.* **2012**, *21*, 226–234. [CrossRef]
153. Ma, J.; Dai, H.; Liu, H.; Du, W. Effects of cutting stages and additives on the fermentation quality of triticale, rye and oat silage in Qinghai-Tibet Plateau. *Agronomy* **2022**, *12*, 3113. [CrossRef]
154. Svezhentsov, A.I.; Gorlach, S.A.; Martynyak, S.V. *Compound Feeds, Premixes, BMVD for Animals and Poultry*; Art Press: Dnepropetrovsk, Ukraine, 2008. (In Russian)
155. Bedford, M.R.; Morgan, A.J. The use of enzymes in poultry diets. *Worlds Poult. Sci. J.* **1996**, *52*, 61–68. [CrossRef]
156. .Brenes, A.; Centeno, C.; Viveros, A.; Arija, I. Effect of enzyme addition on the nutritive value of high oleic acid sunflower seeds in chicken diets. *Poult. Sci.* **2008**, *87*, 2300–2310. [CrossRef] [PubMed]
157. Datsyuk, I.; Bondarenko, V. Slaughter indicators of young pigs when feeding BVMD "Activities" and premix "Intremix". *Sci. Eur.* **2021**, *3*, 10–23. [CrossRef]
158. Bouyeh, M.; Gevorgian, O.X. Influence of different levels of lysine, methionine and protein on the performance of laying hens after peak. *J. Anim. Vet. Adv.* **2011**, *10*, 532–537. [CrossRef]
159. Kislukhina, O.V. *Enzymes in Food and Feed Production*; DeLi Print: Moscow, Russia, 2002; Available online: https://www.livelib.ru/book/1000022283-fermenty-v-proizvodstve-pischi-i-kormov-o-v-kisluhina (accessed on 20 November 2023). (In Russian)

160. Zarghi, H.; Golian, A. Effect of triticale replacement and enzyme supplementation on performance and blood chemistry of broiler chickens. *J. Anim. Vet. Adv.* **2009**, *8*, 1316–1321. Available online: https://www.researchgate.net/profile/Heydar-Zarghi/publication/202542972_Effect_of_Triticale_Replacement_and_Enzyme_Supplementation_on_Performance_and_Blood_Chemistry_of_Broiler_Chickens/links/5847c87308ae61f75de16818/Effect-of-Triticale-Replacement-and-Enzyme-Supplementation-on-Performance-and-Blood-Chemistry-of-Broiler-Chickens.pdf (accessed on 10 February 2024).
161. Gaviley, O.V.; Katerynych, O.O. The influence of triticale on biochemical processes in the body of chickens. *Sučasne Ptahìvnictvo Modern Poult. Farming* **2017**, *5–6*, 12–16. (In Ukrainian)
162. Gaviley, O.V.; Katerynych, O.O. Technology of Rational Use of Triticale in Poultry Feed. In *Triticale—Culture of the 21st Century, Abstracts of Reports of the International Scientific and Practical Conference, Kharkiv, Ukraine, 4–6 July 2017*; V.Ya. Yuriev Institute of Plant Production: Kharkiv, Ukraine, 2017; pp. 47–48. (In Ukrainian)
163. Scholtyssek, S.; Knorr, R. The effect of a cellulolytic enzyme mixture in the broiler feed with triticale and rye. *Arch. Geflugelk.* **1987**, *51*, 10–15.
164. Ibatullin, I.I.; Bashchenko, M.I.; Zhukorskyi, O.M.; Kandyba, V.M.; Rudenko, E.V.; Ionov, I.A.; Mikhalchenko, S.A.; Tsvigun, A.T.; Shapovalov, S.O.; Zolotaryov, A.P.; et al. *Handbook on Complete Feeding of Farm Animals*; Ibatullin, I.I., Zhukorskyi, O.M., Eds.; Ahrarna Nauka: Kyiv, Ukraine, 2016; Available online: https://dspace.hnpu.edu.ua/server/api/core/bitstreams/283ec959-7166-4f94-8549-4535fd01c64c/content (accessed on 20 November 2023). (In Ukrainian)
165. Fontes, C.M.G.A.; Ponte, P.I.P.; Reis, T.C.; Soares, M.C.; Gama, L.T.; Dias, F.M.V.; Ferreira, L.M.A. A family 6 carbohydrate-binding module potentiates the efficiency of a recombinant xylanase used to supplement cereal-based diets for poultry. *Br. Poult. Sci.* **2004**, *45*, 648–656. [CrossRef] [PubMed]
166. Gao, F.; Jiang, Y.; Zhou, G.H.; Han, Z.K. The effects of xylanase supplementation on growth, digestion, circulating hormone and metabolite levels, immunity and gut microflora in cockerels fed on wheat-based diets. *Br. Poult. Sci.* **2007**, *48*, 480–488. [CrossRef] [PubMed]
167. Kalmendal, R.; Tauson, R. Effects of a xylanase and protease, individually or in combination, and an ionophore coccidiostat on performance, nutrient utilization, and intestinal morphology in broiler chickens fed a wheat-soybean meal-based diet. *Poult. Sci.* **2012**, *91*, 1387–1393. [CrossRef]
168. Wu, Y.B.; Ravindran, V.; Thomas, D.G.; Birtles, M.J.; Hendriks, W.H. Influence of method of whole wheat inclusion and xylanase supplementation on the performance, apparent metabolisable energy, digestive tract measurements and gut morphology of broilers. *Br. Poult. Sci.* **2004**, *45*, 385–394. [CrossRef]
169. Perttilä, S.; Valaja, J.; Partanen, K.; Jalava, T.; Kiiskinen, T.; Palander, S. Effects of preservation method and β-glucanase supplementation on ileal amino acid digestibility and feeding value of barley for poultry. *Br. Poult. Sci.* **2001**, *42*, 218–229. [CrossRef]
170. Wang, Z.R.; Qiao, S.Y.; Lu, W.Q.; Li, D.F. Effects of enzyme supplementation on performance, nutrient digestibility, gastrointestinal morphology, and volatile fatty acid profiles in the hindgut of broilers fed wheat-based diets. *Poult. Sci.* **2005**, *84*, 875–881. [CrossRef]
171. Olukosi, O.A.; Cowieson, A.J.; Adeola, O. Influence of enzyme supplementation of maize–soyabean meal diets on carcase composition, whole-body nutrient accretion and total tract nutrient retention of broilers. *Br. Poult. Sci.* **2008**, *49*, 436–445. [CrossRef]
172. García, M.; Lázaro, R.; Latorre, M.A.; Gracia, M.I.; Mateos, G.G. Influence of enzyme supplementation and heat processing of barley on digestive traits and productive performance of broilers. *Poult. Sci.* **2008**, *87*, 940–948. [CrossRef]
173. Partridge, G. Feed enzyme technology aims to reduce feed costs. *Food Int.* **2008**, *4*, 36–38.
174. Pettersson, D.; Åman, P. Effects of enzyme supplementation of diets based on wheat, rye or triticale on their productive value for broiler chickens. *Anim. Feed Sci. Technol.* **1988**, *20*, 313–324. [CrossRef]
175. Guerreiro, C.I.P.D.; Ribeiro, T.; Ponte, P.I.P.; Lordelo, M.M.S.; Falcao, L.; Freire, J.P.B.; Ferreira, L.M.A.; Prates, J.A.M.; Fontes, C.M.G.A. Role of a family 11 carbohydrate-binding module in the function of a recombinant cellulase used to supplement a barley-based diet for broiler chickens. *Br. Poult. Sci.* **2008**, *49*, 446–454. [CrossRef] [PubMed]
176. Pan, L.; Huang, K.H.; Middlebrook, T.; Zhang, D.; Bryden, W.L.; Li, X. Rumen degradability of barley, oats, sorghum, triticale, and wheat in situ and the effect of pelleting. *Agriculture* **2021**, *11*, 647. [CrossRef]
177. Preston, C.M.; McCracken, K.J.; McAllister, A. Effect of diet form and enzyme supplementation on growth, efficiency and energy utilisation of wheat-based diets for broilers. *Br. Poult. Sci.* **2000**, *41*, 324–331. [CrossRef] [PubMed]
178. Venäläinen, E.; Valkonen, E.; Jalava, T.; Valaja, J. Effect of Crimped Barley on the Performance of Broiler Chickens. In Proceedings of the 16th European Symposium on Poultry Nutrition, Strasbourg, France, 26–30 August 2007; European Federation of WPSA Branches, Working Group No. 2 Nutrition: Strasbourg, France, 2007; pp. 79–82. Available online: https://wpsa.fr/images/publications/espn_2007_proceedings.pdf (accessed on 20 November 2023).
179. Bratyshko, N.I.; Prytulenko, O.V.; Tereshchenko, O.V.; Gaviley, O.V.; Hrytsenko, R.B. Economic Efficiency of Using Triticale Extrudates in Breeding Poultry. In Proceedings of the V International Conference "Poultry Industry-2009", Sudak, Ukraine, 21–24 September 2009; pp. 36–40. Available online: https://www.researchgate.net/publication/342781962_Bratisko_NI_Pritulenko_OV_Teresenko_OV_Gavilej_OV_Gricenko_RB_Ekonomicna_efektivnist_vikoristanna_ekstrudantiv_tritikale_v_godivli_pleminnoi_ptici_Materiali_V_Miznarodnoi_konferencii_Ptahivnictvo-2009 (accessed on 20 November 2023). (In Ukrainian)

180. Hajnal, E.J.; Babič, J.; Pezo, L.; Banjac, V.; Čolović, R.; Kos, J.; Krulj, J.; Pavšič-Vrtač, K.; Jakovac-Strajn, B. Effects of extrusion process on Fusarium and Alternaria mycotoxins in whole grain triticale flour. *LWT* **2022**, *155*, 112926. [CrossRef]
181. Bratyshko, N.I.; Gaviley, O.V.; Prytulenko, O.V.; Tereshchenko, O.V.; Polyakova, L.L.; Hrytsenko, R.B. A method of increasing the efficiency of using triticale in feeding laying hens. *Ptahìvnictvo Poult. Farming* **2009**, *63*, 101–109. Available online: http://avianua.com/archiv/ptahivnictvo/63/11.pdf (accessed on 20 November 2023). (In Ukrainian)
182. Jadhao, S.B.; Chandramoni; Tiwari, C.M.; Khan, M.Y. Efficiency of utilization of energy from maize- and broken rice-based diets in old White Leghorn and Rhode Island Red laying hens. *Br. Poult. Sci.* **1999**, *40*, 275–283. [CrossRef]
183. Kovbasa, V.M.; Myronova, N.G.; Shapoval, S.V. Changes in the carbohydrate complex of cereals during extrusion. *Vìsnik agrarnoï nauki Bull. Agric. Sci.* **1997**, *3*, 55–57. (In Ukrainian)
184. Gulati, P.; Brahma, S.; Rose, D.J. Chapter 13–Impacts of extrusion processing on nutritional components in cereals and legumes: Carbohydrates, proteins, lipids, vitamins, and minerals. In *Extrusion Cooking*, 2nd ed.; Ganjyal, G.M., Ed.; Elsevier Inc., Woodhead Publ., Cereals & Grains Association: Duxford, UK, 2020; pp. 415–443. [CrossRef]
185. Makowska, A.; Baranowska, H.M.; Michniewicz, J.; Chudy, S.; Kowalczewski, P.Ł. Triticale extrudates–Changes of macrostructure, mechanical properties and molecular water dynamics during hydration. *J. Cereal Sci.* **2017**, *74*, 250–255. [CrossRef]
186. Bogdanov, G.A.; Zverev, A.I.; Prokopenko, L.S.; Privalo, O.E. *Handbook of Feed and Feed Additives*; Bogdanov, G.A., Ed.; Harvest: Kiev, Ukraine, 1984. (In Russian)
187. Escalante-Aburto, A.; Figueroa-Cárdenas, J.d.D.; Dominguez-Lopez, A.; García-Lara, S.; Ponce-García, N. Multivariate analysis on the properties of intact cereal kernels and their association with viscoelasticity at different moisture contents. *Foods* **2023**, *12*, 808. [CrossRef] [PubMed]