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Early-Maturity Wheat as a Highly Valuable Feed Raw Material with Prebiotic Activity

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Abstract: This work is devoted to the study of the dynamics of changes in the composition of the heap of cereal crops during maturation and identifying the optimal stage at which the grain heap has a high feed value. We studied the grain heap of winter wheat of the Admiral variety, perennial winter wheat (*Tritritrigia*) of the Pamyati Lyubimovoy variety, and gray wheatgrass of the Sova variety for the amino acid composition, and protein, moisture, iron, phosphorus, selenium, zinc, starch, and vitamin E contents. Cereal crops harvested at the hard wax ripeness stage demonstrated a 3–4% higher protein content, along with increased levels of certain amino acids and minerals such as iron and selenium. The grain heap of hard waxy ripeness wheat was studied for prebiotic properties. The study found that it increases the number of lactic acid bacteria in the intestinal microbiota and therefore is a promising prebiotic for agriculture. Based on this study, the recommended concentration of grain heap of waxy ripeness wheat as a feed additive is 1%.

Keywords: compound feed; feed; feed raw materials; prebiotics; vegetable protein; wax ripeness; wheat

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1. Introduction

Cereal crops play an important role in the feed industry. They are a source of carbohydrates; in some feed recipes, their share is more than 50% of all components. Due to its properties [1], wheat is used more often than others in feed recipes: wheat protein has a high digestibility compared to other cereal crops (barley, rye, and oats); the gluten contained in wheat acts not only as a source of protein, but also as a binding component, which is especially important in the production of granulated fish feed; the extrusion of wheat leads to starch hydrolysis, resulting in the formation of sugars and dextrins, which are easily absorbed by the animal’s body; in addition, extrusion improves the organoleptic properties of the product. According to FAO Director General Dr. QU Dongyu [2], 40% of arable land is used for feeding livestock. This enhances the sustainability of the agro-industrial complex by optimizing land use. Therefore, improving crop cultivation technologies and using new crops will contribute to the sustainable development of the agro-industrial complex in the world.

Low-protein wheat grain is used as fodder. Previous studies by scientists from different countries [3–15] have shown that wheat grain at early stages of maturity (from early milk to late wax ripeness) contains higher levels of protein and gluten—by 3–4% on average. These data allow us to state that it is advisable to use grain before full maturity for the production of compound feed.

In the work by [3], the authors present the results of their study on the dynamics of changes in the grain nature, vitreousness, and the protein and gluten content in the spring soft wheat variety, Baganskaya 85 (a mid-season variety). The authors conclude that harvesting wheat grain earlier or later than the stage of late wax ripeness worsens the quality of the crop. Having conducted research in 2010 and 2011, the authors determined that, despite changes in grain quality depending on meteorological conditions, the highest content of nutritional components is observed at the late wax ripeness stage.

In another study [4], the scientists compared the chemical composition of three spelt varieties at the milk ripeness stage and the full ripeness stage. They examined the spelt for minerals (micronutrients (Cu, Zn, Mn, Fe, Na, B) and macronutrients (N, P, K, Mg, Ca)), replaceable and essential amino acids, and the fatty acid composition. The results of the study showed that, at the milk ripeness stage, the content of useful nutrients was higher than at the full ripeness stage. Studying spelt at the milk and full ripeness stages, Berihuete-Azorín et al. [5] revealed that, at the milk ripeness stage, spelt grain has a higher protein content and a lower carbohydrate content than at the stage of full ripeness. The studies showed that, at the milk ripeness stage, spelt grain has a higher protein content and a lower carbohydrate content than at the stage of full ripeness.

As a result of changes in the composition of wheat grain during ripening, Özkaya et al. [6] made the following conclusions: the accumulation of protein and functional compounds (proteins, fiber, fructans, phenolic substances, and antioxidants) occurs before the milk ripeness stage, after which they are spent on grain growth and ripening, and proportionally decrease by the stage of full ripeness.

The research results do not allow for reliable conclusions about the dynamics of changes in the grain composition during ripening, nor can they identify the optimal stage at which the highest nutrient content occurs.

– Some studies indicate higher quality indicators of grain at the milk ripeness stage, while other studies provide higher quality indicators at the stage of late wax ripeness;
– In some studies, only two stages were analyzed—early (milk) and full ripeness. This is a fairly wide range of studies, which does not fully reflect the change in grain at the early stages: the early milk ripeness phase, late milk ripeness phase, early wax ripeness stage, and middle and end of wax ripeness. A more detailed study will allow us to more accurately determine the stage at which the grain has a higher quality and to obtain the maximum benefit from its use;
– The studies were conducted in different years and regions, and they used different scales to denote the ripeness phases. A large number of authors used the BBCH scale to analyze the changes in the grain composition during ripening [7–15]. The use of this scale in the present study will unify the data on changes in the grain composition during ripening and provide a clearer overall picture.

In addition to grain, an additional source of feed raw materials can be the non-grain part of the crop—the chaff. Previously, this type of feed raw material was actively used in the feed industry. Chaff was a secondary raw material that was obtained after cleaning the grain heap at stationary grain processing points. Currently, the cleaning of the mown grain mass is carried out directly in grain harvesters and the non-grain part remains in the field. It is advisable to use grain intended for feed purposes together with chaff without separating it. This will increase the amount of feed raw material harvested and reduce the cost by eliminating the grain cleaning process. Previously, scientists [3–15] studied the dynamics of grain change. No studies have been conducted on changes in the quality indicators of the grain heap (grain and chaff).

Perennial grain crops (for example, the perennial winter wheat (*Trititrigia*) of the Pamyati Lyubimovoy and blue wheatgrass of the Sova) are promising feed and food raw materials, since they are drought-resistant, resistant to many diseases, and have a positive effect on the condition of the soil, thus increasing its fertility. More detailed information on perennial crops is presented in previous studies [16]. A study of the changes in the quality of these crops during the ripening process has also not been conducted previously.

In addition to the nutritional value, such feed raw materials may have prebiotic properties. Agricultural raw materials of plant origin contain polysaccharides, which can be natural prebiotics [17]. According to data from [18–21], prebiotics should be resistant to digestion in the upper gastrointestinal tract, stimulate the growth of beneficial bacteria, and have a positive effect on consumer health. Essential oils and medicinal plants [22,23], mushrooms [24], algae [25], etc., are most often considered as a source of prebiotics. We studied the grain heap of early waxy ripeness wheat for prebiotic properties. We found that it can be an accessible and relatively cheap raw material for the production of prebiotic preparations.

Based on the above, the aim of this study is to identify the optimal stage of grain maturation, at which the highest content of beneficial nutrients is observed, and to conduct an analysis for the presence of prebiotic properties in such potentially valuable feed raw materials.

2. Materials and Methods

2.1. Sowing and Harvesting Grain Crops

To study the changes in the grain composition during ripening, the following three types of grain were taken: winter wheat of the Admiral variety (*Triticum aestivum*), perennial winter wheat (*Trititrigia*) of the Pamyati Lyubimovoy variety (*Trititrigia cziczinii Tzvel.*), and blue wheatgrass of the Sova variety (*Thinopyrum intermedium*). Annual winter wheat is a classic type of grain crop used everywhere. The choice of the Admiral wheat variety is justified by its prevalence in the South of Russia.

The sowing of the studied crops was carried out in the fields of the educational and experimental site of Don State Technical University in the village of Rassvet, Rostov Region, Russian Federation. The experimental plots consist of ordinary carbonate heavy loamy chernozem soil.

The soil analysis was carried out according to the following parameters:

- The humus content (%) was determined by the method of I.V. Tyurin. The method is based on the oxidation of organic matter with chromic acid to form carbon dioxide;
- The total nitrogen (mg/kg) was determined by the ionometric method. The method involves extracting nitrates from the soil with a 1% solution of potassium alum and measuring the activity of the nitrate ion using an ion-selective electrode;
- To determine the mobile phosphorus and potassium (mg/kg), the Kirsanov method for determining mobile phosphorus and potassium compounds was used. The method is based on the extraction of mobile compounds of phosphorus and potassium from the soil with a solution of hydrochloric acid of a molar concentration of 0.2 mol/dm^3, and the subsequent determination of phosphorus on a photoelectrocolorimeter and potassium on a flame photometer;
- The pH of the salt extract. The method is based on obtaining an aqueous extract by extracting cations, nitrates, and mobile sulfur from the soil with a solution of

potassium chloride and a potentiometric determination of the pH using a glass electrode.

During the entire vegetation period, the following three soil fertilizations were performed: when sowing seeds, using ammophos in the amount of 100 kg/ha (12 kg N/ha and 52 kg P/ha); in the tillering phase and in the pipe emergence phase, using ammonium nitrate in the amount of 70 kg/ha (24 kg N/ha). Harvesting was carried out in 5 stages (growth phases are presented according to the BBCH scale [7–15]): 77—late milk ripeness (Figure 1), 83—early wax ripeness, 87—hard wax ripeness, 89—full ripeness, 92—over-ripeness. The choice of these stages was based on previous studies [3–15], where scientists examined the dynamics of changes in the grain composition from milk ripeness to full ripeness and over-ripening on the root. The choice of the BBCH scale is justified by its wide popularity throughout the world; it is used both in the scientific field and in practice in the field of agriculture and horticulture, as well as in phenology, as a complex science of the environment, meteorology, and climatology [15]. The harvesting of grain crops at the early stages of ripeness cannot be carried out with a classic grain harvester. For this purpose, a new stripper–threshing unit was used for harvesting grain crops of different ripeness phases [26,27].

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

Figure 1. Harvesting of cereal crops at the early stages of maturity: (**a**) stripping and threshing unit for harvesting cereal crops; (**b**) grain heap of wheat at the early stages of maturity.

As a result of harvesting, a heap of wheat grain was obtained (Figure 1b), which was crushed and subjected to physicochemical analysis.

2.2. Physicochemical Analysis of Harvested Grain Heap

In order to obtain a homogeneous mass for conducting the physicochemical analysis, the obtained grain heap samples were thoroughly mixed and ground in a laboratory mill, the LZM-M2 (Laboratoroff, Voronezh, Russia). The obtained samples were tested for the following quality indicators:

- The mass fraction of moisture (%) was determined by the drying method. The essence of the method lies in drying the sample portion to a constant mass at a temperature of 105 °C;
- The mass fraction of protein (%) was determined by the Kjeldahl method. The protein content was calculated based on the total nitrogen content using a nitrogen-to-protein conversion factor of 6.25;
- The mass fraction of phosphorus (%) was determined by the photometric method. The essence of the method lies in sample mineralization by dry or wet ashing with

the formation of orthophosphoric acid salts, and the subsequent photometric determination of phosphorus in the form of a yellow-colored compound—a heteropoly acid formed in an acidic medium in the presence of vanadate and molybdate ions;

- The mass fraction of proteinogenic amino acids (lysine, arginine, tyrosine, phenylalanine, histidine, leucine, isoleucine, methionine, valine, proline, threonine, serine, alanine, cystine, aspartic acid, glutamic acid, and tryptophan) (%) was determined by capillary electrophoresis. The essence of the method lies in the decomposition of the sample for analysis by acid (for all amino acids except tryptophan) or alkaline (for tryptophan) hydrolysis with the conversion of amino acids into free forms, obtaining the phenylthiocarbamyl derivatives of amino acids, their further separation, and quantitative determination by capillary electrophoresis;
- The content of iron and zinc (mg/kg) was determined by the atomic absorption method. The method is based on the mineralization of the product by dry or wet ashing, and the determination of the concentration of the element in the mineralizate solution by flame atomic absorption;
- The selenium content (mg/kg) was determined by the fluorimetric method. The essence of the method lies in the mineralization of the analyzed sample, the conversion of selenium from organic and inorganic forms into selenite ion, the reaction of selenite ion with the reagent 2,3-diaminonaphthalene in an acidic medium to form 4,5-benzopiazoselenol, its extraction with hexane, and measuring the fluorescence intensity of the resulting extract.
- The mass fraction of starch (%) was determined by the Bertrand method. The essence of the method lies in the ability of reducing sugars to reduce divalent copper in an alkaline medium to copper (I) oxide, which is oxidized with ferric ammonium alum followed by titration of the reduced divalent iron with a solution of potassium permanganate;
- The content of vitamin E (mg/kg) was determined by high-performance liquid chromatography with fluorimetric detection. The method is based on the isolation of polycyclic aromatic hydrocarbons from the analyzed sample with their subsequent quantitative determination by high-performance liquid chromatography with fluorimetric detection.

2.3. Study of Grain Heap of Wheat of Early Stages of Maturity for Prebiotic Activity

After the physicochemical analysis, samples of wheat grain heaps of different maturity stages were frozen to conduct studies of the prebiotic activity.

The effect of wheat grain heaps of early-maturity stages on the microbiota of birds was studied in an artificial intestinal environment. The artificial intestinal medium was previously developed by our team [22,28]. The composition of the medium per 1 L is as follows: soy protein (Kompanioncity, St. Petersburg, Russia)—20 g; water-soluble starch (Chimreactivsnab, Ufa, Russia)—0.5 g; unrefined sunflower oil (Yug Rusi, Rostov-on-Don, Russia)—30 mL; Tween 80 (Chimpharmproduct, St. Petersburg, Russia)—1.5 mL; $MgSO_4$—0.5 g; NaCl—5 g; K_2HPO_4—0.5 g; $MnSO_4$—0.05 g; $FeSO_4$—0.05 g (all salts: Chimpharmproduct, St. Petersburg, Russia).

The preparation method involves heating water and vegetable oil in a drying oven to 80 °C. The oil is then poured into a flask where the medium will be prepared, Tween 80 is added, and the mixture is vigorously shaken. Hot water is then gradually added (5–10 mL at a time) while continuously shaking. The next portion of water is added only after the suspension has been homogenized. The amount of water added each time is then increased to 30–50 mL. Afterward, the remaining components are added and the mixture is autoclaved. This preparation method ensures that the oil does not lose its micellar structure after autoclaving.

Liquid artificial intestinal medium was poured into sterile 250 mL flasks at 100 mL to ensure minimal contact with air and the height of the liquid column. In each of the flasks, except for the control, wheat grain heaps of early-maturity stages were added at concentrations of 0.1%, 0.25%, 0.5%, 0.75%, 1%, 2%, and 5% (depending on the experimental variant). Then, intestinal bacteria were added to the flasks in the form of a suspension prepared from the starter. The starter included the contents of the cecum of several birds that did not receive pro- and prebiotics, as well as antibiotics, about 1 cm^3 in volume, stored at −80 °C. For each experiment, the cecum of a new bird was used. The contents were diluted with 10 mL of sodium chloride at a concentration of 0.9% and added to flasks in 1 mL portions. The flasks were then incubated at 42 °C for 3 days, and the microbiota growth data were recorded on the 3rd day. The pH level was also measured.

The amount of intestinal bacteria was determined by the spread plate method of bacterial inoculation, in the amount of 3 replicates for each nutrient medium for each dilution under study. The amount of bifidobacteria was studied by seeding the suspension in a semi-liquid nutrient medium.

To determine the amount of *Lactobacillus* bacteria, we used the MRS medium (LenReaktiv), *Bifidobacterium*—a medium for isolating bifidobacteria (HiMedia), *Enterococcus*—a medium for isolating enterococci (HiMedia), *E. coli*—Endo medium (HiMedia), and *Staphylococcus*—medium No. 10 (LenReaktiv). The microorganisms were counted on the second day.

In order to evaluate the effect of milk ripeness wheat on the microbiota of other birds, a model of the microbiota of the cecum of quail was studied. To determine the effect of the grain heap of early-ripeness wheat on lactobacilli, the grain heap of early-ripeness wheat with actual moisture content at concentrations of 0.5%, 0.75%, and 1% was added to the artificial intestinal nutrient medium of quail.

In order to check whether the activity of milk ripeness wheat changes after drying in the SSh-200 Bossert oven (Bossert, Moscow, Russia), wheat in amounts of 1 g, 0.75 g, and 0.5 g (which corresponds to concentrations of 1%, 0.75%, and 0.5%) was dried in a dry-heat oven at a temperature of 80 °C. MRS medium was also prepared. Then, a daily culture of *Limosilactobacillus frumenti* KL31 was added and incubated for 2 days at a temperature of 42 °C. The pH level was then determined.

2.4. Statistical Analysis

Each sample was analyzed within 24 h after harvesting. Each sample was analyzed in triplicate. The final result was the arithmetic mean of three repeated determinations. The difference between parallel measurements did not exceed the values characteristic of each method. The obtained results were statistically analyzed using a one-way ANOVA, and the least significant differences were calculated using Tukey's test with an error rate of 5%.

The correlation between the different strains' properties was calculated using the Pearson correlation coefficient.

The Statistica 10.0 and Microsoft Excel 2016 software were used for the calculations.

3. Results

3.1. Results of the Study of Changes in the Composition of a Heap of Cereal Crops During the Maturation Process

The results of the amino acid composition of the grain heap are presented in Figures 2–4.

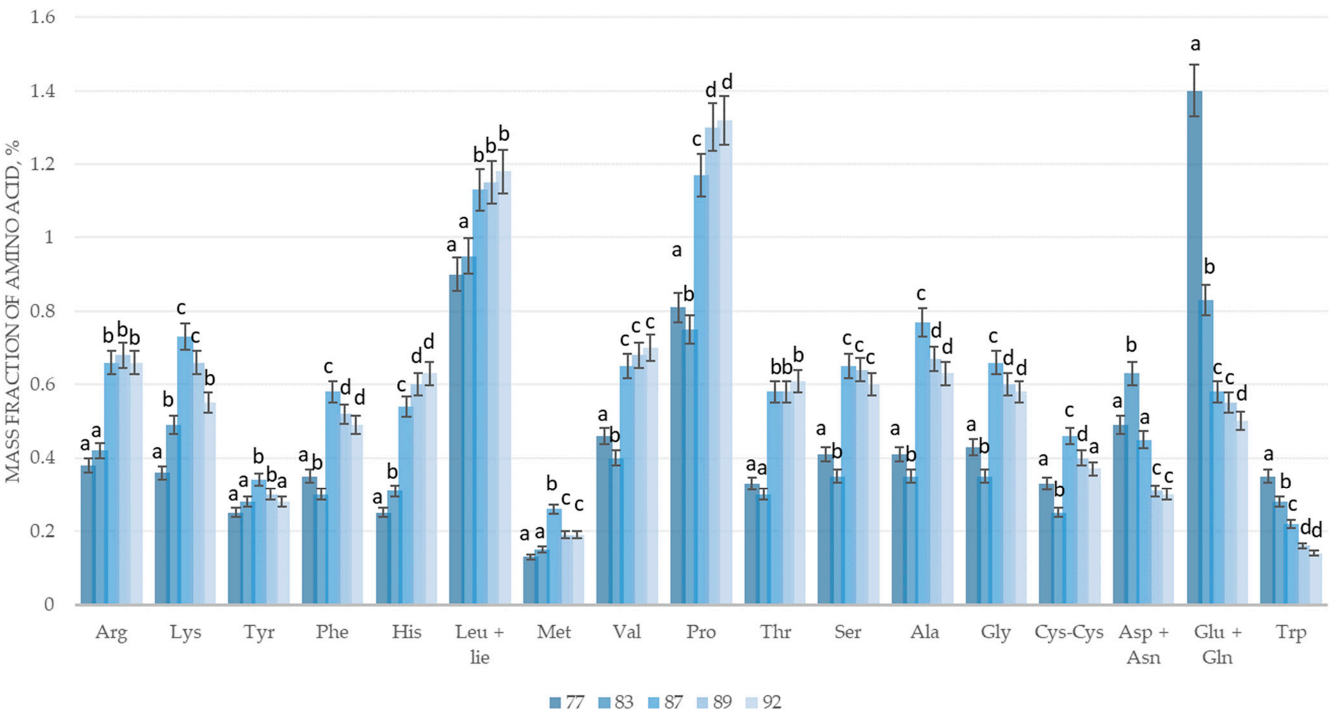

Figure 2. Changes in the amino acid composition of the grain heap of the Admiral wheat variety during the ripening process: 77—late milk ripeness, 83—early wax ripeness, 87—hard wax ripeness, 89—full ripeness, and 92—over-ripeness. Arg—arginine, Lys—lysine, Tyr—tyrosine, Phe—phenylalanine, His—histidine, Leu+Iie—leucine + isoleucine, Met—methionine, Val—valine, Pro—proline, Thr—threonine, Ser—serine, Ala—alanine, Gly—glycine, Cys-Cys—cysteine, Asp+Asn—asparagine + aspartic acid, Glu+Gln—glutamine + glutamic acid, and Trp—tryptophan; a–d—different letters indicate significant differences between ripening phases ($p < 0.05$).

The results of the study show that the milk ripeness stage (stage 77 on the BBCH scale) has the highest content of glutamic acid, glutamine, and tryptophan, and, during the transition to wax ripeness, there is a sharp decrease, which continues after full ripeness.

The content of aspartic acid and asparagine in the early wax ripeness phase (83 on the BBCH scale) reaches its peak values, after which, like glutamic acid, glutamine, and tryptophan, they decrease before and after full ripeness.

The highest amount of amino acids lysine, tyrosine, phenylalanine, methionine, alanine, glycine, and cystine in the grain heap of wheat of the Admiral variety is observed at the stage of hard wax ripeness (stage 88 on the BBCH scale), after which there is a smooth decrease before and after full ripeness. The content of histidine, leucine, isoleucine, valine, proline, threonine, and serine increases throughout the growing season.

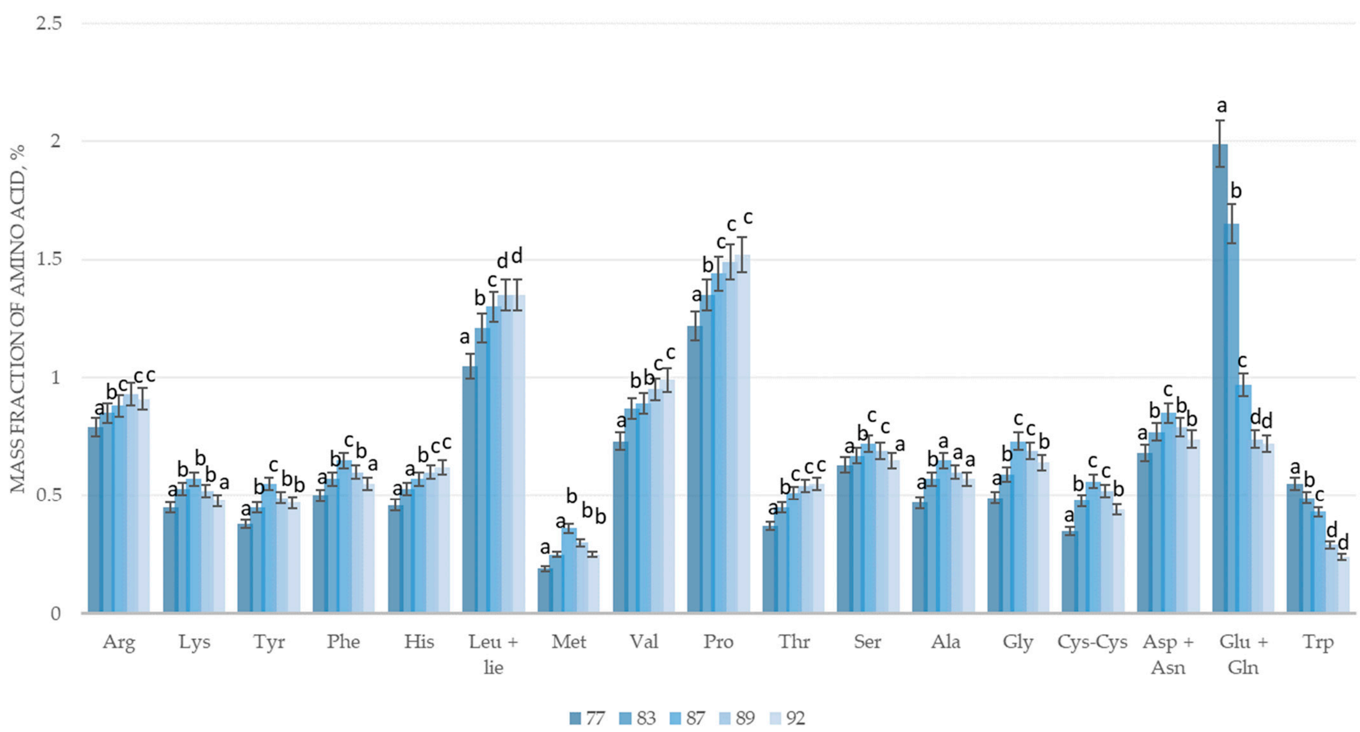

Figure 3. Changes in the amino acid composition of the grain heap of perennial winter wheat (*Trititrigia*) of the Pamyati Lyubimovoy variety during the ripening process: 77—late milk ripeness, 83—early wax ripeness, 87—hard wax ripeness, 89—full ripeness, and 92—over-ripeness. Arg—arginine, Lys—lysine, Tyr—tyrosine, Phe—phenylalanine, His—histidine, Leu+Iie—leucine + isoleucine, Met—methionine, Val—valine, Pro—proline, Thr—threonine, Ser—serine, Ala—alanine, Gly—glycine, Cys-Cys—cysteine, Asp+Asn—asparagine + aspartic acid, Glu+Gln—glutamine + glutamic acid, and Trp—tryptophan; a–d—different letters indicate significant differences between ripening phases ($p < 0.05$).

The dynamics of changes in the amino acid composition of the grain heap of perennial winter wheat (*Trititrigia*) of the Pamyati Lyubimovoy variety is similar to the dynamics of annual winter wheat of the Admiral variety. The amino acid composition of perennial wheat is higher than that of annual winter wheat of the Admiral variety by an average of 1.5–2.0 times. In addition, the accumulation of amino acids in perennial wheat occurs more smoothly than in annual wheat.

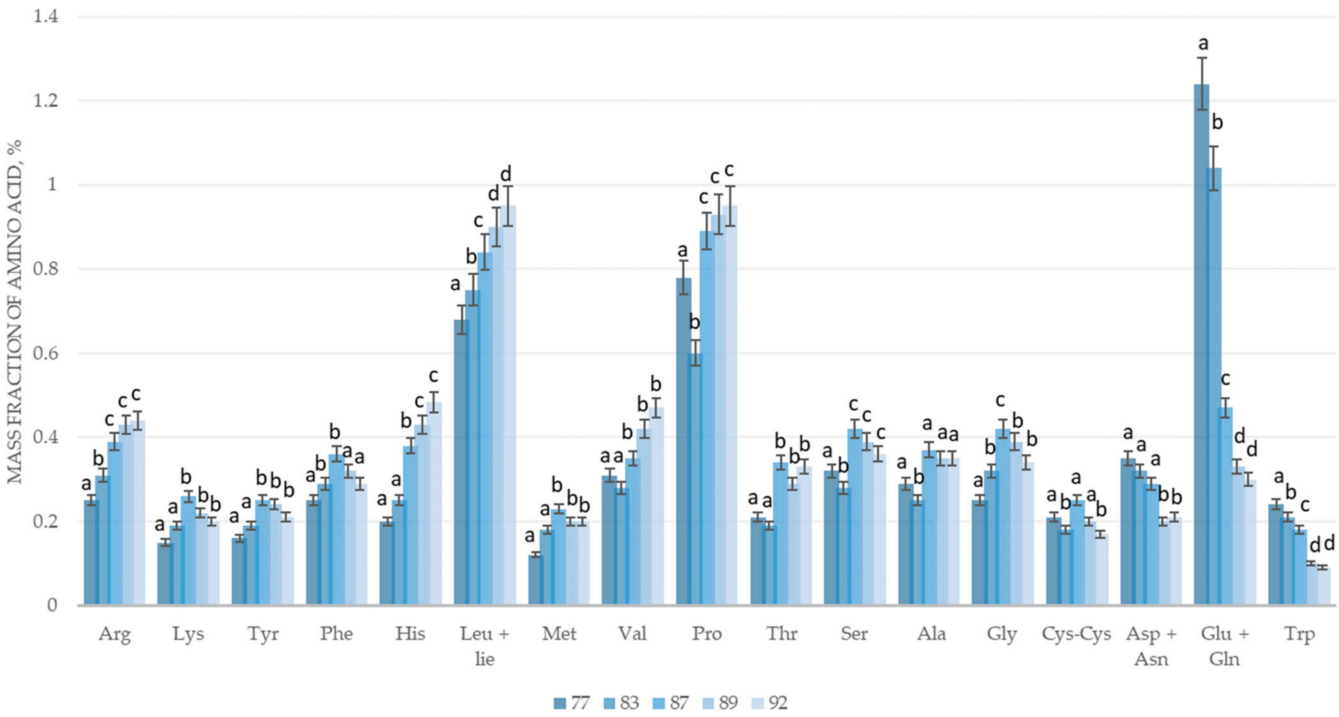

Figure 4. Changes in the amino acid composition of the grain heap of the perennial wheatgrass variety Sova during the ripening process: 77—late milk ripeness, 83—early wax ripeness, 87—hard wax ripeness, 89—full ripeness, and 92—over-ripeness. Arg—arginine, Lys—lysine, Tyr—tyrosine, Phe—phenylalanine, His—histidine, Leu+Iie—leucine + isoleucine, Met—methionine, Val—valine, Pro—proline, Thr—threonine, Ser—serine, Ala—alanine, Gly—glycine, Cys-Cys—cysteine, Asp+Asn—asparagine + aspartic acid, Glu+Gln—glutamine + glutamic acid, and Trp—tryptophan; a–d—different letters indicate significant differences between ripening phases ($p < 0.05$).

In terms of the content and dynamics of amino acid changes, the Sova variety of blue wheatgrass is similar to the Admiral variety of annual winter wheat. The Sova variety of blue wheatgrass, in comparison with the previous two analyzed crops, has a lower content of amino acids. It contains a low amount of lysine and tyrosine—more than two times. The dynamics of changes in the amino acid composition of the Sova variety of blue wheatgrass is similar to the previous crops, the Admiral variety of annual winter wheat and the Pamyati Lyubimovoy variety of *Tritritrigia* wheat, with the exception of aspartic acid and asparagine. Its amount reaches peak values at the stage of late milk ripeness and continues to decrease until full ripeness. Tables 1–8 present the results of the study of the content of protein, moisture, iron, phosphorus, selenium, zinc, starch, and vitamin E in a heap of cereal crops.

Table 1. Change in the mass fraction of protein (%) in a heap of cereal crops during the maturation process.

Sample Name, %	Growth Phase According to BBCH Scale				
	77	83	87	89	92
Grain heap of one-year winter wheat of the "Admiral" variety	12.65 ± 0.41 [a]	12.32 ± 0.40 [a]	13.49 ± 0.43 [b]	13.17 ± 0.42 [b]	12.87 ± 0.41 [a]
Grain heap of perennial winter wheat (*Trititrigia*) of the "Pamyati Lyubimovoy" variety	12.93 ± 0.41 [a]	15.01 ± 0.47 [b]	16.11 ± 0.50 [c]	15.76 ± 0.49 [b]	15.41 ± 0.48 [b]
Grain heap of the blue wheatgrass variety "Sova"	8.74 ± 0.30 [a]	8.78 ± 0.30 [a]	9.12 ± 0.31 [b]	9.0 ± 0.30 [b]	8.45 ± 0.29 [a]

a–c—different superscript letters in the row indicate significant differences between ripening phases ($p < 0.05$).

Table 1 shows that all three of the studied crops have higher peak protein values at the hard wax ripeness stage (stage 87 on the BBCH scale), after which they decrease by 0.1–0.5%. Also, after full ripeness, the protein content in the grain heap decreases by 0.3–0.4%.

Table 2. Change in the moisture content (%) in a heap of cereal crops during ripening.

Sample Name	Growth Phase According to BBCH Scale				
	77	83	87	89	92
Grain heap of one-year winter wheat of the Admiral variety	66.58 ± 1.88 [b]	46.40 ± 2.03 [a]	41.20 ± 2.00 [a]	15.80 ± 1.37 [c]	11.90 ± 0.92 [c]
Grain heap of perennial winter wheat (*Trititrigia*) of the Pamyati Lyubimovoy variety	65.78 ± 1.90 [b]	44.32 ± 2.02 [a]	40.31 ± 1.99 [a]	14.92 ± 1.34 [c]	10.60 ± 0.92 [c]
Grain heap of the Sova variety of wheatgrass	55.12 ± 2.02 [b]	39.78 ± 1.98 [a]	35.22 ± 1.92 [a]	13.78 ± 1.29 [c]	10.40 ± 0.95 [c]

a–c—different superscript letters in the row indicate significant differences between ripening phases ($p < 0.05$).

The dynamics of moisture change in the heap of cereal crops demonstrates a smooth decrease to the wax ripeness stage and a sharp decrease in moisture before the onset of full ripeness. The grain of winter wheat of the Admiral variety is larger than that of the other two studied crops, as a result of which the grain heap of wheat of the Admiral variety has higher moisture.

Table 3. Change in the iron content (mg/kg) in a heap of cereal crops during maturation.

Sample Name	Growth Phase According to BBCH Scale				
	77	83	87	89	92
Grain heap of one-year winter wheat of the Admiral variety	43.65 ± 4.37 [a]	46.25 ± 4.63 [a]	51.39 ± 5.14 [b]	34.30 ± 3.43 [c]	33.23 ± 3.32 [c]
Grain heap of perennial winter wheat (*Trititrigia*) of the Pamyati Lyubimovoy variety	44.08 ± 4.41 [a]	46.17 ± 4.62 [a]	51.97 ± 5.20 [b]	36.19 ± 3.62 [c]	35.78 ± 3.58 [c]
Grain heap of the Sova variety of wheatgrass	46.45 ± 4.65 [a]	49.21 ± 4.92 [a]	53.14 ± 5.31 [b]	55.68 ± 5.57 [b]	54.12 ± 5.41 [b]

a–c—different superscript letters in the row indicate significant differences between ripening phases ($p < 0.05$).

The iron content increases smoothly up to the stage of hard wax ripeness. Then, having reached peak values in this phase of 51–53 mg/kg, there is a sharp decrease in the grain heap of annual winter wheat of the Admiral variety and perennial winter wheat (*Trititrigia*) of the Pamyati Lyubimovoy variety. In these crops, the iron content in the phase of full ripeness is lower than in the stage of late milk ripeness. In the grain heap of the Sova variety of blue wheatgrass, iron accumulates up to the onset of full ripeness and only slightly decreases after the onset of full ripeness (stage 92 on the BBCH scale).

Table 4. Change in the phosphorus content (%) in a heap of cereal crops during maturation.

Sample Name	Growth Phase According to BBCH Scale				
	77	83	87	89	92
Grain heap of one-year winter wheat of the Admiral variety	0.12 ± 0.03 [a]	0.15 ± 0.03 [a]	0.17 ± 0.04 [a]	0.18 ± 0.04 [a]	0.37 ± 0.05 [b]
Grain heap of perennial winter wheat (*Trititrigia*) of the Pamyati Lyubimovoy variety	0.17 ± 0.04 [a]	0.21 ± 0.04 [b]	0.23 ± 0.04 [b]	0.27 ± 0.05 [b]	0.4 ± 0.05 [c]
Grain heap of the Sova variety of wheatgrass	0.22 ± 0.04 [a]	0.27 ± 0.05 [a]	0.30 ± 0.05 [b]	0.36 ± 0.05 [b]	0.49 ± 0.05 [c]

a–c—different superscript letters in the row indicate significant differences between ripening phases ($p < 0.05$).

The phosphorus content increases slowly throughout all of the stages under study. A sharp increase (almost two times) occurs after full ripeness and reaches 0.37–0.49%.

Table 5. Change in the selenium content (mg/kg) in a heap of cereal crops during maturation.

Sample Name	Growth Phase According to BBCH Scale				
	77	83	87	89	92
Grain heap of one-year winter wheat of the Admiral variety	0.23 ± 0.06 [a]	0.34 ± 0.07 [b]	0.51 ± 0.08 [c]	0.36 ± 0.07 [b]	0.29 ± 0.07 [a]
Grain heap of perennial winter wheat (*Trititrigia*) of the Pamyati Lyubimovoy variety	0.20 ± 0.04 [a]	0.31 ± 0.07 [b]	0.45 ± 0.08 [c]	0.31 ± 0.07 [b]	0.25 ± 0.07 [b]
Grain heap of the Sova variety of wheatgrass	0.32 ± 0.07 [a]	0.40 ± 0.08 [b]	0.55 ± 0.08 [c]	0.49 ± 0.08 [b]	0.44 ± 0.08b [b]

a–c—different superscript letters in the row indicate significant differences between ripening phases ($p < 0.05$).

The selenium content reaches its peak values at the stage of hard wax ripeness. After full ripeness, the selenium content decreases almost by two times in the two studied samples—the grain heap of annual winter wheat of the Admiral variety and the grain heap of perennial winter wheat (*Trititrigia*) of the Pamyati Lyubimovoy variety. In the grain heap of the Sova variety of wheatgrass, the selenium content practically does not change after full ripeness. This is probably due to the presence of a large amount of non-grain part in the grain heap of the Sova variety of wheatgrass, which is typical for this type of crop (the Sova variety of wheatgrass has a large amount of green mass in comparison with the other grain crops [21]).

Table 6. Change in the zinc content (mg/kg) in a heap of cereal crops during maturation.

Sample Name	Growth Phase According to BBCH Scale				
	77	83	87	89	92
Grain heap of one-year winter wheat of the Admiral variety	34.16 ± 3.42 [a]	31.09 ± 3.11 [a]	35.61 ± 3.56 [a]	26.34 ± 2.63 [b]	23.07 ± 2.31 [b]
Grain heap of perennial winter wheat (*Trititrigia*) of the Pamyati Lyubimovoy variety	38.47 ± 3.85 [a]	35.49 ± 3.55 [a]	37.98 ± 3.80 [a]	32.74 ± 3.27 [b]	30.55 ± 3.06 [b]
Grain heap of the Sova variety of wheatgrass	40.12 ± 4.01 [a]	38.22 ± 3.82 [b]	41.03 ± 4.10 [b]	37.12 ± 3.71 [b]	35.54 ± 3.55 [b]

a–b—different superscript letters in the row indicate significant differences between ripening phases ($p < 0.05$).

The zinc content at the early stages of ripeness (milk and wax 77–87) remains practically unchanged. After full ripeness, the amount decreases slightly by 4–9 mg/kg.

Table 7. Change in the starch content (%) in a heap of cereal crops during maturation.

Sample Name	Growth Phase According to BBCH Scale				
	77	83	87	89	92
Grain heap of one-year winter wheat of the Admiral variety	59.65 ± 9.34 ^{a}	61.22 ± 9.57 ^{a}	63.71 ± 9.95 ^{a}	67.83 ± 10.56 ^{b}	67.23 ± 10.47 ^{b}
Grain heap of perennial winter wheat (*Trititrigia*) of the Pamyati Lyubimovoy variety	55.17 ± 8.67 ^{a}	59.74 ± 9.35 ^{a}	62.95 ± 9.83 ^{b}	65.12 ± 10.16 ^{b}	64.75 ± 10.10 ^{b}
Grain heap of the Sova variety of wheatgrass	30.17 ± 4.92 ^{a}	32.23 ± 5.22 ^{a}	38.47 ± 6.16 ^{a}	38.95 ± 6.23 ^{b}	40.70 ± 6.50 ^{b}

a–b—different superscript letters in the row indicate significant differences between ripening phases ($p < 0.05$).

Starch accumulation in the grain occurs throughout the growing season and reaches peak values at full maturity. The grain heap of the Sova variety of wheatgrass contains one-and-sixth-tenth times less starch than the other two analyzed samples.

Table 8. Change in the vitamin E content (mg/kg) in a heap of cereal crops during the maturation process.

Sample Name	Growth Phase According to BBCH Scale				
	77	83	87	89	92
Grain heap of one-year winter wheat of the Admiral variety	6.63 ± 1.14 ^{a}	3.35 ± 0.58 ^{b}	4.71 ± 0.81 ^{c}	30.22 ± 5.21 ^{d}	38.98 ± 6.72 ^{d}
Grain heap of perennial winter wheat (*Trititrigia*) of the Pamyati Lyubimovoy variety	6.78 ± 1.17 ^{a}	3.55 ± 0.61 ^{b}	5.02 ± 0.87 ^{c}	35.77 ± 6.17 ^{d}	41.44 ± 7.14 ^{f}
Grain heap of the Sova variety of wheatgrass	6.25 ± 1.08 ^{a}	2.91 ± 0.50 ^{b}	3.76 ± 0.65 ^{c}	25.84 ± 4.46 ^{d}	33.72 ± 5.81 ^{f}

a–d,f—different superscript letters in the row indicate significant differences between ripening phases ($p < 0.05$).

The content of vitamin E also increases after full ripeness. Vitamin E is fat-soluble and is found mainly in the embryo, so its amount increases sharply after full ripeness, when the embryo is fully formed (an increase from 4.71 to 30.22 mg/kg). The change in the quality indicators of the grain is similar in all three samples.

3.2. Results of the Study of Prebiotic Activity of Grain Heap of Wheat of Early Stages of Maturity

To study the prebiotic activity, we used a grain heap of the Admiral wheat of the hard wax ripeness stage (87 on the BBCH scale), since it is at this stage that the highest content of all the nutrients studied in this work is observed.

3.2.1. Study of the Effect of High Concentrations of Milk Ripeness Wheat in the Chicken Microbiota Model

An artificial intestinal environment of a chicken was used as a model medium. Concentrations of 5%, 2%, and 1% were used, since concentrations of 2% were the most effective in our previous studies with essential oil plant cakes. The results are presented in Table 9.

Table 9. The effect of high concentrations of waxy wheat grain heap on the number of microorganisms of different groups under the conditions of the chicken microbiota model, CFU/mL.

Name of Bacteria	Control	1%	2%	5%
Lactic acid bacteria	$1.2 \pm 0.2 \cdot 10^7$	$4.7 \pm 0.2 \cdot 10^8$ *	$4.4 \pm 0.3 \cdot 10^8$ *	$2.0 \pm 0.3 \cdot 10^8$ *
Bifidobacterium	10^6	10^4 *	10^4 *	10^4 *
Enterococcus	$4.0 \pm 0.4 \cdot 10^6$	$9.4 \pm 0.1 \cdot 10^4$ *	$1.3 \pm 0.2 \cdot 10^4$ *	$1.1 \pm 0.2 \cdot 10^3$ *
E. coli	$5.7 \pm 0.5 \cdot 10^6$	-	-	-
Staphylococcus	$6.1 \pm 0.2 \cdot 10^6$	$9.6 \pm 0.3 \cdot 10^4$ *	$3.3 \pm 0.4 \cdot 10^4$ *	$3.0 \pm 0.3 \cdot 10^3$ *
Bacillus	$3.2 \pm 0.3 \cdot 10^6$	$6.0 \pm 0.3 \cdot 10^3$ *	$7.3 \pm 0.3 \cdot 10^2$ *	-
pH	7.1	6.2 *	5.9 *	5.2 *

* significantly different to the control at $p < 0.05$.

The presented data show that the waxy wheat grain heap had a significant effect on the chicken microbiota. The number of lactic acid bacteria increased, while the pH level of the medium decreased. The number of opportunistic microorganisms decreased and the number of E. coli fell to values below the threshold for this technique. On the other hand, the concentration of bifidobacteria and bacilli also decreased.

In general, an excessively high concentration of waxy wheat grain heap, despite the increase in the number of lactic acid bacteria, has a negative effect on the microbiota, reducing the diversity and completely suppressing some groups of microorganisms. Nevertheless, such shifts show the high potential of waxy wheat grain heap as a prebiotic.

3.2.2. Study of Low Concentrations of Milky Ripeness Wheat in the Chicken Microbiota Model

An artificial chicken intestinal environment was used as a model medium. Concentrations of 0.1%, 0.25%, and 0.5% were used. The addition of sugar at a concentration of 0.1% was also used as a positive control. It was necessary to determine whether the observed effect was based on the content of prebiotic components or only on the content of simple sugars in the composition of the wheat grain heap. The results obtained are presented in Table 10.

Table 10. The effect of low concentrations of waxy wheat grain heap on the number of microorganisms of different groups under the conditions of the chicken microbiota model, CFU/mL.

Name of Bacteria	Control	0.1%	0.25%	0.5%	Sugar
Lactic acid bacteria	$1.8 \pm 0.2 \cdot 10^7$	$1.0 \pm 0.4 \cdot 10^7$	$7.0 \pm 0.2 \cdot 10^7$	$1.4 \pm 0.5 \cdot 10^8$ *	$3.3 \pm 0.3 \cdot 10^7$
Bifidobacterium	10^8	10^8	10^8	10^8	10^8
Enterococcus	$1.2 \pm 0.3 \cdot 10^8$	$1.2 \pm 0.3 \cdot 10^8$	$1.3 \pm 0.3 \cdot 10^8$	$6.0 \pm 0.3 \cdot 10^7$ *	$9.1 \pm 0.4 \cdot 10^7$
E. coli	$1.1 \pm 0.2 \cdot 10^8$	$6.0 \pm 0.3 \cdot 10^7$	$1.0 \pm 0.4 \cdot 10^8$	$1.0 \pm 0.5 \cdot 10^8$	$1.6 \pm 0.4 \cdot 10^8$
Staphylococcus	$5.5 \pm 0.2 \cdot 10^7$	$6.0 \pm 0.2 \cdot 10^7$	$9.7 \pm 0.3 \cdot 10^7$	$3.2 \pm 0.3 \cdot 10^7$	$5.2 \pm 0.2 \cdot 10^7$
Bacillus	$1.3 \pm 0.3 \cdot 10^7$	$9.5 \pm 0.5 \cdot 10^6$	$8.0 \pm 0.5 \cdot 10^6$	$2.3 \pm 0.4 \cdot 10^7$	$1.7 \pm 0.3 \cdot 10^7$
pH	7.0	6.9	7.2	6.7 *	7.1

* significantly different to the control at $p < 0.05$.

The presented data show that the microbiota responded more weakly to the introduction of waxy wheat grain heap, where concentrations of 0.1% and 0.25% did not have a reliable effect on the number and ratio of microorganism groups in the chicken microbiota. A concentration of 0.5% led to an increase in the number of lactobacilli and a decrease in the number of enterococci.

Sugar, even in a deliberately overestimated concentration, did not have a reliable effect on the chicken microbiota, which means that the effect we observed is not associated with the presence of simple sugars in wheat.

3.2.3. Study of Average Concentrations of Milk-Ripe Wheat in the Chicken Microbiota Model

At this stage, the concentrations that seemed the most promising after the first two stages were evaluated—0.5%, 0.75%, and 1%. The results are presented in Table 11.

Table 11. The effect of a grain heap of waxy wheat on the number of microorganisms of different groups under the conditions of the chicken microbiota model, CFU/mL.

Name of Bacteria	Control	0.5%	0.75%	1%
Lactic acid bacteria	$4.5 \pm 0.2{\cdot}10^7$	$1.3 \pm 0.4{\cdot}10^8$ *	$1.5 \pm 0.3{\cdot}10^8$ *	$7.6 \pm 0.2{\cdot}10^8$ *
Bifidobacterium	10^8	10^8	10^8	10^8
Enterococcus	$3.5 \pm 0.3{\cdot}10^7$	$2.7 \pm 0.4{\cdot}10^7$	$7.4 \pm 0.3{\cdot}10^6$ *	$8.0 \pm 0.3{\cdot}10^6$ *
E. coli	$2.5 \pm 0.4{\cdot}10^8$	$1.2 \pm 0.2{\cdot}10^7$ *	$2.0 \pm 0.3{\cdot}10^6$ *	$4.0 \pm 0.4{\cdot}10^6$ *
Staphylococcus	$9.4 \pm 0.3{\cdot}10^6$	$2.2 \pm 0.3{\cdot}10^6$	$4.0 \pm 0.4{\cdot}10^6$	$6.6 \pm 0.3{\cdot}10^6$
Bacillus	$3.1 \pm 0.2{\cdot}10^7$	$4.0 \pm 0.3{\cdot}10^6$ *	$3.4 \pm 0.5{\cdot}10^6$ *	$1.0 \pm 0.3{\cdot}10^6$ *
pH	6.9	6.6	6.4 *	6.0 *

* significantly different to the control at $p < 0.05$.

The presented data show that the effect of introducing waxy wheat grain heap is weaker than the first experiment and is comparable to the second. All three concentrations caused an increase in the number of lactobacilli. At a concentration of 0.5%, a decrease in the number of *E. coli* and bacilli is noted; at concentrations of 0.75% and 1%, *E. coli*, enterococci, and bacilli increased.

3.2.4. Study of Waxy Wheat Grain Heap in the Quail Microbiota Model

To assess the effect of waxy wheat grain heap on the microbiota of other birds, a model of quail cecum microbiota was studied. Milky ripeness wheat was used at concentrations of 0.5%, 0.75%, and 1%. The obtained data are presented in Table 12.

Table 12. The influence of a grain heap of waxy ripeness wheat on the number of microorganisms of different groups under the conditions of the quail microbiota model, CFU/mL.

Name of Bacteria	Control	0.5%	0.75%	1%
Lactic acid bacteria	$1.3 \pm 0.3{\cdot}10^5$	$2.2 \pm 0.4{\cdot}10^7$ *	$2.9 \pm 0.3{\cdot}10^7$ *	$7.4 \pm 0.3{\cdot}10^7$ *
Bifidobacterium	10^6	10^6	10^6	10^6
Enterococcus	$6.5 \pm 0.2{\cdot}10^8$	$6.9 \pm 0.3{\cdot}10^8$	$6.7 \pm 0.2{\cdot}10^8$	$4.5 \pm 0.4{\cdot}10^8$
E. coli	$6.5 \pm 0.4{\cdot}10^8$	$5.2 \pm 0.3{\cdot}10^8$	$6.1 \pm 0.4{\cdot}10^8$	$8.9 \pm 0.3{\cdot}10^8$
Staphylococcus	$1.2 \pm 0.2{\cdot}10^8$	$1.8 \pm 0.2{\cdot}10^8$	$2.7 \pm 0.3{\cdot}10^8$	$2.9 \pm 0.5{\cdot}10^8$
Bacillus	$1.3 \pm 0.3{\cdot}10^7$	$1.3 \pm 0.4{\cdot}10^7$	$2.3 \pm 0.5{\cdot}10^7$	$1.4 \pm 0.3{\cdot}10^7$
pH	7.2	6.8	6.5 *	6.4 *

* significantly different to the control at $p < 0.05$.

The presented data show that the effect of waxy wheat grain heap on the microbiota of quails is weaker than on the microbiota of chickens. Among the groups representing opportunistic microorganisms, no reliable change in the number was noted when introducing waxy wheat grain heap. No change in the number of bifidobacteria was noted either. At the same time, the number of lactobacilli and other lactic acid bacteria increased significantly, by more than two orders of magnitude, which repeats the trend noted in experiments on the model chicken environment.

3.2.5. Study of Dry Grain Heap of Waxy Ripeness Wheat for the Number of Microorganisms of Different Groups Under the Conditions of the Quail Microbiota Model, CFU/mL

In order to check whether the activity of the grain heap of waxy ripeness wheat changes after drying, wheat in amounts of 1 g, 0.75 g, and 0.5 g (which correspond to concentrations of 1%, 0.75%, and 0.5%) was dried in a dry-heat oven at a temperature of 80 °C. The moisture content of the wheat was 32%. The results obtained are shown in Table 13. The concentrations were recalculated for the actual moisture content of the grain heap of waxy ripeness wheat.

Table 13. The effect of dry grain heap of waxy wheat on the number of microorganisms of different groups under the conditions of the quail microbiota model, CFU/mL.

Name of Bacteria	Control	0.5%	0.75%	1%
Lactic acid bacteria	$1.3 \pm 0.2 \cdot 10^5$	$1.0 \pm 0.3 \cdot 10^7$ *	$1.4 \pm 0.2 \cdot 10^7$ *	$1.5 \pm 0.3 \cdot 10^7$ *
Bifidobacterium	10^6	10^6	10^6	10^6
Enterococcus	$6.5 \pm 0.4 \cdot 10^8$	$5.0 \pm 0.3 \cdot 10^8$	$8.2 \pm 0.3 \cdot 10^8$	$7.4 \pm 0.4 \cdot 10^8$
E.coli	$6.5 \pm 0.3 \cdot 10^8$	$2.3 \pm 0.2 \cdot 10^8$	$7.1 \pm 0.4 \cdot 10^8$	$6.2 \pm 0.2 \cdot 10^8$
Staphylococcus	$1.2 \pm 0.2 \cdot 10^8$	$3.4 \pm 0.4 \cdot 10^8$	$4.5 \pm 0.3 \cdot 10^8$	$3.5 \pm 0.3 \cdot 10^8$
Bacillus	$1.3 \pm 0.3 \cdot 10^7$	$1.0 \pm 0.3 \cdot 10^7$	$2.4 \pm 0.4 \cdot 10^7$	$6.3 \pm 0.2 \cdot 10^7$
pH	7.2	6.7	6.4 *	6.3 *

* significantly different to the control at $p < 0.05$.

As in the previous case, no reliable differences were noted in the number of microorganism groups from the control values, with the exception of the number of lactic acid bacteria, which increased by two orders of magnitude.

3.2.6. Effect of Waxy Wheat Grain Heap on Lactobacilli

Data on the effect of waxy wheat grain heap on the pH of the medium after incubation with *Limosilactobacillus frumenti* KL31 are presented in Table 14.

Table 14. The pH of the media with and without the addition of waxy wheat grain heap during incubation of *Limosilactobacillus frumenti* KL31 in an artificial intestinal medium (AIM).

Nutrient Medium	pH
MRS	3.1
AIM	6.9
AIM + 0.5% of wet wheat	6.7
AIM + 0.75% of wet wheat	6.2
AIM + 1% of wet wheat	5.9
AIM + 0.5% of dry wheat	6.6
AIM + 0.75% of dry wheat	6.3
AIM + 1% of dry wheat	6.1

It can be noted that, on the nutrient medium rich in sugars (MRS), a significant decrease in the pH level is observed during the incubation of *Limosilactobacillus frumenti* KL31. On the artificial intestinal medium containing trace amounts of simple sugars, the pH remains neutral. At the same time, the introduction of both wet and dry grain heap of waxy ripeness wheat leads to an increase in the production of lactic acid by

Limosilactobacillus frumenti KL31. This means that the grain heap of waxy ripeness wheat contains carbohydrates that can serve as an energy source for lactobacilli.

4. Discussion

The obtained data confirmed the results of previous studies [3–15]: the protein content is higher at the early stages of maturity, by 3–4% on average. In addition, data were obtained confirming the negative impact of increasing the harvesting time on the volume and quality of the crop: in addition to the problem of self-shedding, which is a natural process of agricultural crops that results in significant losses, the quality of such grain also deteriorates. Therefore, the timely harvesting of cereal crops will allow for the obtainment of a high-quality crop with minimal losses [27]. It is at the stage of hard wax ripeness that the grain accumulates the maximum amount of protein, which is consistent with the results of studies [3]. Grain harvesting at this stage will improve the quality of feed raw materials and increase the actual grain yield due to timely harvesting and minimal losses from self-shedding, which will contribute to the sustainable development of the agro-industrial complex (in particular, the feed industry) in the world [2]. From an economic point of view, energy costs for harvesting by stripping on the root with a stripping and threshing unit are reduced [27], which, in turn, has a positive effect on the cost of production; a decrease in losses from self-shedding also has a positive effect on the cost of the resulting crop.

The analysis of changes in the amino acid composition of cereal crops shows similar dynamics: at the stage of milk ripeness (stage 77 on the BBCH scale), the maximum content of glutamic acid, glutamine, and tryptophan is observed; the content of aspartic acid and asparagine at the stage of the early phase of wax ripeness (83 on the BBCH scale) reaches its peak values; the greatest amount of amino acids, including lysine, tyrosine, phenylalanine, methionine, alanine, glycine, and cystine, in a heap of grain crops is observed at the stage of hard wax ripeness (stage 87 on the BBCH scale); the content of histidine, leucine, isoleucine, valine, proline, threonine, and serine increases throughout the growing season. This is consistent with the data [4], where scientists studied spelt at the milk and full ripeness stages. They found that, in the grain at the milk ripeness stage, the content of lysine, methionine, alanine, and tyrosine was higher than at the stage of full ripeness. In our studies, the obtained data were clarified, as a result of which it was revealed that these amino acids continue to increase until hard wax ripeness (stage 87 on the BBCH scale).

Lizin and methionine are the most important indispensable amino acids that are involved in the processes of reducing oxidation in the body of animals, thus contributing to increasing the productivity and strengthening the immune system [27,28]. Limiting (critical) amino acids play an important role in the nutrition of animals and fish, the deficiency or excess of which affects the absorption of other amino acids. Limiting amino acids differ in different animal species. Thus, for birds, the limiting amino acids are methionine and cystine; for pigs, it is lysine. These amino acids reach their peak values at wax ripeness (stage 87 on the BBCH scale). In plant materials, tryptophan, methionine, and lysine most often act as limiting amino acids. A deficiency of limiting amino acids in feed can lead to metabolic disorders, decreased immunity, obesity, and greater feed consumption [27,29]. Therefore, it is advisable to use a heap of cereal crops at the stage of hard wax ripeness, when their quantity at this stage is maximum.

The iron content in the grain heap of annual winter wheat of the Admiral variety and perennial winter wheat (*Trititrigia*) of the Pamyati Lyubimovoy variety peak values are observed at the stage of hard wax ripeness. In the grain heap of the Sova variety of blue wheatgrass, the iron concentration increases towards the stage of full ripeness (stage 89 on the BBCH scale), which is consistent with the data on the change in the amount of iron in spelt [4].

In two of the three spelt varieties, the phosphorus content is higher at the milk stage of ripeness [4]. According to our data, the phosphorus content slowly increases throughout all of the studied stages. A sharp increase (almost two times) occurs after full ripeness and reaches 0.37–0.49%.

The zinc content at the early stages of ripeness (milk and wax stages 77–87) remains virtually unchanged. After full ripeness, the amount decreases slightly by 4–9 mg/kg. This is consistent with the data on zinc changes in spelt [4].

Thus, the dynamics of changes in the main nutritional nutrients of cereal crops, such as starch and protein, are similar for both wheat (annual and perennial) and spelt [3–15], regardless of the conditions and growing zone.

The dynamics of changes in mineral substances vary somewhat, which may be due to the weather conditions, soil composition, and fertilization [30–33]. The introduction of a grain heap of waxy ripeness wheat stably led to an increase in the number of lactic acid bacteria. The number of opportunistic microorganisms decreased, while the number of E. coli fell to values below the threshold for this method. On the other hand, the concentration of bifidobacteria and bacilli also decreased. These results are similar to those of [23], where *Panax ginseng* was used as a prebiotic. Also, as with the use of grain piles, there is an increase in lactobacilli. It is noted that, when using a grain pile, there is a decrease in the number of *E. coli* and bacilli, which is consistent with the data from [22–25], where the use of algae, medicinal plants, and fungi as a prebiotic feed additive also inhibits pathogenic microflora and allows the microbiota to be restored after exposure to negative factors.

5. Conclusions

A heap of cereal crops at the stage of hard wax ripeness is a valuable and economically accessible new feed raw material. Due to the increased content of a number of proteinogenic amino acids, including lysine, methionine, and cystine—important limiting amino acids—the share of amino acids introduced as a feed additive is reduced, which will help to reduce the cost of feed. In addition, such raw materials contain more iron and selenium than fully ripe grain. A distinctive feature of this feed raw material is its high prebiotic activity for lactobacilli and other lactic acid bacteria. Harvesting grain at this stage of ripeness allows for harvesting within agro-technological timeframes and reduces grain losses from self-shedding. Thus, harvesting grain before full ripeness and its use in the compound feed industry corresponds to the principles of a closed-loop economy, as well as the principles of sustainable agricultural development. In future research, we plan to conduct a series of experiments aimed at developing a method for determining the purpose of grain that has not yet reached full maturity (forage or food purposes) in field conditions, and also to conduct an economic assessment of the application of this method of harvesting and the use of raw materials in the production of compound feed.

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