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One strain – different effects: *Kluyveromyces marxianus* probiotic and postbiotic forms' effect on growth and metabolism of piglets during postweaning and rearing periods

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The postweaning period is one of the most critical stages in piglet rearing, characterized by metabolic instability, impaired intestinal function and an increased diarrhea risk. Under these conditions, the efficacy of feed additives is determined not only by their origin but also by their functional form. The objective of the study was to evaluate the effect of probiotic and postbiotic forms of yeast supplements, derived from a single strain of *Kluyveromyces marxianus*, on the performance, feed conversion efficiency, and piglets' physiological condition between 5 and 80 days of age. The piglets were divided into three groups: a control group, an experimental group receiving a probiotic supplement, and an experimental group receiving a postbiotic supplement, which were fed age-appropriate doses as part of pre-starter and starter compound feed. It was found that the nature of the animals' physiological response depended significantly on the form of the supplement. The probiotic form produced a rapid effect in the early postweaning period, as evidenced by increased live weight gain, higher feed intake, and a reduction in the diarrhea incidence. At the same time, the postbiotic form was characterized by a more stable and prolonged effect, accompanied by improved parameters of protein metabolism, increased albumin and globulin blood levels, and reduced transaminase activity, indicating better metabolic adaptation of the organism. It is fundamentally important that the same biological basis (the yeast strain *Kluyveromyces marxianus*) gives rise to different types of physiological response depending on its form: a short-term adaptive response in the case of a probiotic and a longer-lasting systemic response in the case of a postbiotic. The results obtained indicate that the functional form of yeast supplements is a key factor in their efficacy, and that the use of a postbiotic form may provide more consistent support for the piglets' health and performance in the postweaning period. Future research should be focused on the effects of the probiotic culture and the postbiotic hydrolysate of *Kluyveromyces marxianus* on redox homeostasis, particularly by assessing markers of oxidative stress and the antioxidant system in piglets at different ages.

Keywords: *Kluyveromyces marxianus*; probiotic; postbiotic; weaned piglets; protein metabolism; aminotransferases.

Introduction

Intensive pig farming systems have reached a point where traditional approaches to maintaining productivity no longer guarantee consistent results. On the one hand, the genetic potential of modern breeds requires the most precise provision of nutrients, taking into account not only diet composition but also absorption characteristics, feeding regimes, and the interaction of feed components (Chassé et al., 2021; Prudyus et al., 2022). On the other hand, restrictions on the use of antibiotics and the rise in antibiotic resistance significantly limit the tools available for animal health management. In these circumstances, alternative approaches are becoming increasingly important, particularly the use of probiotic and biotechnological feed additives capable of supporting productivity and physiological stability (Yirga, 2015; Elghandour et al., 2020).

The early postnatal period is particularly vulnerable, as piglets transition from milk to solid feed. During this time, several critical processes occur simultaneously: the restructuring of the gut microbiota, the maturation of the immune system, the development of enzymatic activity, and adaptation to new substrates. Any imbalance during this period rapidly manifests as clinical symptoms (diarrhea, reduced feed intake, and loss of weight gain), which are directly linked to impaired intestinal barrier function and changes in the structure of tight junctions in the epithelium (Su et al., 2022; Prudyus et al., 2023). This is precisely why the search for functional dietary components capable of stabilising these processes is not merely relevant, but a key task in modern animal nutrition. In this context, yeast-based biotechnological products are garnering attention as systemic modulators of the digestive and immune environments. Unlike traditional feed additives, their action is not limited to the nutrients supply – they influence the interaction between the microbiota, the intestinal epithelium, and the immune system. Yeast-based products have been integrated into feed technology multiple times, yet their functional role is considerably broader than has traditionally been recognized. Various forms based on them (probiotics, prebiotics, postbiotics) differ not only formally but also fundamentally in their mechanisms of action (Fan et al., 2025), which determines the nature of their biological effect.

Probiotics exert their effects by altering the gut microbiome, establishing stable microbial populations, and interacting with the immune system within the intestinal lymphoid tissue. As a result, not only is feed digestibility altered, but also the barrier function of the mucous membrane and the inflammatory processes intensity (Ding et al., 2021).

Therefore, evidence is accumulating regarding the limitations of probiotic strategies, in particular the inconsistency of their effects under conditions of stress or in the presence of an immature immune system, as well as the potential risks associated with the transfer of resistance genes (Pérez-Sotelo et al., 2005). This creates a demand for alternative solutions capable of delivering a more predictable and stable effect. However, findings regarding the efficacy of probiotic strategies in pig farming remain inconsistent. A number of studies have demonstrated improvements in growth performance, gut health, and microbial fermentation following the use of hydrolysed yeast products (Boontiam et al., 2020). At the same time, there are studies where the effect was limited or depended on the dose, the age of the animals, and housing conditions, and the changes in productivity did not reach statistical significance (Molist et al., 2014; Upadhaya et al., 2019). Such a variability suggests that the effectiveness of such approaches is determined not only by the presence of biologically active components, but also by the form in which they are administered.

Among such, alternative yeast-based probiotics are considered, as they are capable of influencing digestion, the immune response, and metabolic processes in animals, thereby reducing the adverse effects of stress and infectious load (Collier et al., 2011; Elghandour et al., 2020), although their potential has only been partially realized. Unlike bacteria, yeasts have a different cellular organization, range of metabolites, and mechanisms of interaction with the host organism. Recent studies show that yeasts classified as GRAS are widely regarded as functional feed additives capable of influencing digestion, the immune response, and metabolic processes (Elghandour et al., 2020; Gorreja et al., 2022; Zang et al., 2024). However, these effects depend to a large extent on the species and strain, making the choice of biological agent a matter of fundamental importance.

Probiotics can modulate the rumen or hindgut microbiota, alter the nature of fermentation, and increase the flow of nutrients to the small intestine, thereby improving the digestibility of the diet (Krehbiel et al., 2003). Some researchers believe that adding probiotics to livestock feed reduces cholesterol levels through the direct uptake of cholesterol compounds by bacteria (Nami et al., 2019). Thus, probiotic supplements can improve fiber digestion, enhancing nutrient uptake, improving livestock health, and increasing livestock production (Arowolo & He, 2018).

In this context, *Kluyveromyces marxianus* stands out as an atypical but promising candidate. It is one of the fast-growing yeast species with high metabolic activity, capable of maintaining viability across a wide range of temperatures and pH levels, including conditions within the gastrointestinal tract (Koukoumaki et al., 2024). At the same time, the results of its use in animal husbandry remain limited and not always consistent, indicating the need to refine the conditions and methods of its application.

The functional potential of this species is not limited to its resistance. *Kluyveromyces marxianus* is capable of fermenting lactose, synthesizing β-galactosidase, and influencing nutrient availability, which is of particular importance in early age (Tullio et al., 2024). Furthermore, its influence on energy metabolism has been established, in particular through the activation of oxidative phosphorylation processes (Xu et al., 2025), which indicates the systemic nature of its action.

In parallel with the development of probiotic approaches, a trend has emerged toward the use of postbiotics – products containing non-viable cells and their metabolites, retaining biological activity (Salminen et al., 2021; Sudaarsan et al., 2024). Their effect is more stable and less dependent on environmental conditions, which is especially important in production systems.

The mechanisms of yeast-based bioproducts action are systemic in nature and involve the regulation of metabolic processes, as reflected in protein metabolism and enzymatic activity changes. The biologically active components of yeast are capable of influencing protein synthesis and energy utilization, which is consistent with changes in total protein and albumin concentrations. Additionally, β-glucans and mannan-oligosaccharides modulate the intestinal barrier and microbiota status, which indirectly manifests as a reduction in the diarrhea incidence and improved feed utilization. Under conditions of increased metabolic load, this may be accompanied by a reduction in the functional load on the liver, which is reflected in the stabilization of transferase activity within physiological ranges.

A particular role is played by yeast-derived postbiotics, which contain β-glucans, mannan-oligosaccharides, peptides and nucleotides. These components are capable of activating innate immunity via mechanisms of microbial structure recognition (Quintin, 2019) and simultaneously supporting protein metabolism and tissue repair processes (Middelkoop et al., 2024), combining metabolic and immune effects.

Despite growing interest in yeast-based products, the question of efficacy of different forms of the same strain remains unresolved. Most studies do not distinguish between probiotic and postbiotic effects, which complicates the interpretation of the results obtained and makes it impossible to clearly determine which specific form is responsible for the observed biological effect. With this in mind, previous studies focused on characterizing the *Kluyveromyces marxianus* strain and assessing its probiotic potential (Matiukha et al., 2024). At the same time, the efficacy of different forms of its application in field conditions remained insufficiently studied.

In this regard, the objective of this study was to determine the differences in the biological effects of a probiotic culture and a postbiotic hydrolysate derived from *K. marxianus* on the performance, feed conversion efficiency, and biochemical blood parameters of piglets during the critical period of early postnatal development.

Materials and methods

During the study, ethical requirements for the use of animals in experimental research were fully observed (Strasbourg, 1986; Kyiv, 2002), and the research methodology was approved by the Bioethics Commission of the Institute of Animal Biology of the NAAS.

The experiment was conducted in field conditions of the pig-complex LLC Ahrocompaniia RATA during the period from day 5 to day 80 of piglets' life. The experiment involved 300 healthy piglets of a three-way hybrid from the genetic company Choice Genetics. From the fifth day of life, three groups of 100 animals each were formed on a randomized basis: the control group (C), experimental group 1 (D1), and experimental group 2 (D2). During the experiment period, the piglets were fed the same basic compound feed, with the differences between the groups in specific feed additives. The basic pre-starter compound feed included wheat bran, barley bran, maize bran, whey, soya protein concentrate, monocalcium phosphate, chalk, and premix. The starter basic compound feed included wheat bran, barley bran, soya meal, sunflower meal, oil, premix, acidifier, and mycotoxin adsorbent.

The control group (C) received a basic diet without feed additives. In group D1, a probiotic feed additive based on the yeast strain *Kluyveromyces marxianus* (KluActive) was added to the diet, and in group D2 a postbiotic supplement (a hydrolysate of yeast cells of the same strain [NutriLys]) was used. These additives were manufactured at Enzym Group facilities. Hereinafter, abbreviated group designations (C, D1, D2) are used in the text and tables, where D1 corresponds to the probiotic form and D2 to the postbiotic form. The experimental design and additive dosing are shown in Table 1.

Table 1
Schematic illustration of animal experimentation

Groups	Compound feed	
	Pre-starter (5–43 days)	Starter (44–80 days)
Control	BD* (basic diet – compound feed)	
Experiment 1 (D1)	BD + 0.4 kg/t Probiotic (KluActive)	BD + 0.3 kg/t Probiotic (KluActive)
Experiment 2 (D2)	BD + 5.0 kg/t Postbiotic (NutriLys)	BD + 3.0kg/t Postbiotic (NutriLys)

Note. The number of animals in each group was n = 100.

The study utilized two yeast-based feed supplements. The probiotic supplement (KluActive) contained viable *K. marxianus* cells at a concentration of over 1×10^{10} CFU/g and was supplied in a granulated form with biocoating, ensuring their stability during storage and passage through the gastrointestinal tract. The postbiotic supplement (NutriLys) was obtained by enzymatic hydrolysis of cells from the same strain and was characterized by the contents of crude protein of over 40%, β-glucans of around 15% and mannan-oligosaccharides of approximately 10%, with a moisture content of no more than 6%.

Biochemical blood analyses were carried out to assess the metabolic status of the piglets. Samples were collected from the animals in each group on days 28, 43, and 80 from the jugular vein into sterile vacuum tubes. After centrifugation at 3,000 rpm for 10 minutes, blood serum was obtained and used for further studies. Analyses were performed in the certified Biolights laboratory using an AU480 automated biochemical analyzer and standard diagnostic kits manufactured by Beckman Coulter Inc. (USA).

Blood serum was analysed for parameters characterizing protein metabolism and liver function. Total protein concentration was determined using the biuret method, albumin levels were measured using standard diagnostic kits, and globulin levels were calculated as the difference between total protein and albumin. Enzymatic activity was assessed by measuring the levels of alanine aminotransferase (ALT) and aspartate aminotransferase (AST), after which the de Ritis ratio (AST/ALT) was calculated.

Throughout the experiment, performance and health parameters of the piglets were recorded. Live weight was measured at appropriate age intervals, followed by the calculation of average daily gain (ADG). At the same time, feed intake was assessed and used to determine the feed conversion ratio (FCR). Additionally, the diarrhea incidence and herd survival were taken into account. Feed intake was determined by recording the amount of feed dispensed and the feed remaining in each group, followed by conversion to a per-head basis.

Statistical analysis of the experimental results was performed using one-way analysis of variance (ANOVA) with Bonferroni correction, as well as Tukey's one-way analysis of variance. The StatPlus software (AnalystSoft Inc., USA) was used for this purpose. The results are presented as mean ± SD (standard deviation). Differences between the groups of animals were considered statistically significant at $P < 0.05$.

Results

To evaluate the effect of probiotic and postbiotic forms of yeast additives based on *Kluyveromyces marxianus* on the piglets' physiological condition, we analyzed the parameters of protein metabolism, blood enzyme activity, as well as the animals' productivity parameters and health status at different ages. The results obtained allow us to trace both the age-related dynamics of changes and the specific effects of each of the studied supplement forms.

With age increasing, a gradual growth in total protein content was observed in the piglets, reflecting the general intensification of metabolic processes characteristic for active growth period (Table 2). At the same time, the nature of this trend varied depending on the type of additive used. On day 28, the differences between the groups were minimal: In the probiotic group, the total protein level exceeded the control by 4.4%, and that in the postbiotic group by 4.6%. By the final stage of the study, these differences had become pronounced (Table 2). In the probiotic group, the total protein level did not differ from the control, whereas in the postbiotic group it was 7.5% higher than the control and 11.2% higher than the probiotic group ($P < 0.05$). The greatest effect was observed in the postbiotic group, indicating a more pronounced accumulation of protein fractions in the blood.

A similar trend, but more pronounced, was observed for albumin levels (Table 1). Following a decrease in the middle of the experiment on day 80, the levels rose in the experimental groups. In the probiotic group, the albumin level exceeded that of the control by 9.8% ($P < 0.05$), whereas in the postbiotic group it exceeded it by 30.7% ($P < 0.05$). This difference indicates a more intensive restoration of albumin-synthesizing function in the animals of this group.

Changes in globulin levels were more consistent, which corresponds to their role in the body's immune responses. At the final stage, the globulin levels were 14.6% higher in the probiotic group and 18.9% higher in the postbiotic group, compared with the control ($P < 0.05$). The highest values were recorded in the postbiotic group, reflecting a general trend toward a more pronounced effect of this form of supplement on the blood protein profile.

Transaminase activity changed throughout the study, showing an age-related upward trend in the control group, which is characteristic of rapid growth and an increased metabolic load (Table 3). The most pronounced differences between the groups were observed on day 80.

During this period, a decrease in ALT activity was recorded in both experimental groups, measuring 32.9% in the probiotic group and 21.0% in the postbiotic group ($P < 0.05$), compared with the control. This indicates a more stable course of metabolic processes in the animals receiving the additives.

Similar changes were observed for AST (Table 3), although with a greater magnitude. Compared with the control, its activity was 55.3% lower in the probiotic group and 56.1% lower in the postbiotic group ($p < 0.05$). In this case, the difference between the experimental groups was minimal, whereas the differences from the control were marked, highlighting the effect of both supplements on the level of enzymatic activity.

The de Ritis index remained stable throughout the study period, and no intergroup differences were observed (Table 3), indicating that there were no changes in the transaminase activity ratio.

Table 2
Biochemical parameters of blood of piglets
that consumed the studied additives with feed (%, x ± SD; n = 6)

Parameters	Groups	Periods of experiment		
		28 days	43 days	80 days
Albumins (ALB), g/L	C	28.21 ± 3.11[a]	25.63 ± 0.97[a]	25.61 ± 0.97[a]
	D1	28.04 ± 2.69[a]	25.51 ± 1.60[a]	28.15 ± 0.62[b]
	D2	27.75 ± 0.69[a]	25.30 ± 3.10[a]	33.49 ± 1.31[bc]
Globulins (GLB), g/L	C	14.63 ± 1.91[a]	22.97 ± 1.58[a]	25.49 ± 2.45[a]
	D1	15.12 ± 2.37[a]	24.43 ± 6.50[a]	29.20 ± 2.28[b]
	D2	15.50 ± 2.12[a]	23.72 ± 7.07[a]	30.31 ± 2.15[bc]
Total protein (TP), g/L	C	41.35 ± 5.71[a]	48.61 ± 2.42[a]	59.36 ± 2.68[a]
	D1	43.16 ± 3.89[a]	48.28 ± 4.16[a]	57.35 ± 2.35[b]
	D2	43.25 ± 1.57[a]	49.02 ± 7.79[a]	63.80 ± 1.94[bc]

Note: different letters within a single parameter of the sample denote groups that differ significantly from one another according to the Tukey test ($P < 0.05$).

Table 3
Transferase activity in piglet serum under the influence
of probiotic and postbiotic supplements (%, x ± SD; n = 6)

Parameters	Groups	Periods of experiment		
		28 days	43 days	80 days
Alanine aminotransferase activity (ALT), U/L	C	45.57 ± 5.52[a]	55.57 ± 16.70[a]	55.49 ± 6.89[a]
	D1	46.58 ± 9.60[a]	50.20 ± 6.72[a]	37.20 ± 11.84[b]
	D2	62.28 ± 18.17[bc]	44.08 ± 5.14[a]	43.85 ± 3.07[c]
Aspartate aminotransferase activity (AST), U/L	C	76.47 ± 9.86[a]	100.74 ± 36.22[a]	169.90 ± 98.13[a]
	D1	86.01 ± 39.80[b]	102.73 ± 45.14[a]	76.00 ± 25.82[b]
	D2	106.09 ± 57.51[bc]	71.13 ± 18.21[a]	74.59 ± 22.04[bc]
De Ritis ratio	C	1.68 ± 0.18[a]	2.00 ± 1.00[a]	3.07 ± 1.00[a]
	D1	1.82 ± 0.58[a]	2.08 ± 1.05[a]	2.05 ± 1.05[a]
	D2	1.78 ± 0.94[a]	1.63 ± 0.46[a]	1.70 ± 0.46[a]

Note: see Table 2.

The piglets' response to the administration of the additives was most pronounced during the early rearing period (5–28 days), which is critical in terms of adaptation to feeding and the development of digestive system (Table 4). At this time, the average live weight gain exceeded that in the control by 20.3% in the probiotic group and by 25.0% in the postbiotic group ($P < 0.05$). The highest gains were observed in the postbiotic group.

In the subsequent period (29–43 days), no statistically significant differences were found between the groups (Table 4), indicating a plateau in the growth rates. Subsequently, the differences did not persist in the probiotic group, whereas in the postbiotic group the effect remained noticeable even at the final stage. During the 44–80-day period, the weight gain in this group exceeded the control by 9.5% ($P < 0.05$).

Table 4
Mean weight gain and the diarrhea incidence in the piglets during the study (%, x ± SD; n = 100)

Parameters	Groups	Periods of experiment		
		5-28 days	29-43 days	44-80 days
Weight gain, kg	C	5.61 ± 0.33[a]	3.70 ± 0.20[a]	17.13 ± 1.36[a]
	D1	6.72 ± 0.22[b]	3.36 ± 0.17[a]	17.07 ± 1.56[a]
	D2	7.01 ± 0.19[c]	3.86 ± 0.12[a]	18.75 ± 2.12[b]
Number of piglets with diarrhea in the litter, heads	C	5.00 ± 2.91[a]	4.00 ± 0.99[a]	–
	D1	1.50 ± 0.79[b]	3.70 ± 1.53[a]	–
	D2	1.00 ± 0.49[bc]	3.00 ± 2.00[a]	–

Note. See Table 2.

Changes in health status were most clearly evident during the early stage (Table 5), when the animals are most susceptible to digestive disorders. Compared with the control, the number of diarrhea cases decreased by 70.0% in the probiotic group and by 80.0% in the postbiotic group ($P < 0.05$). At this stage, the effect of the supplements was the greatest.

Table 5
Indicators of consumption of pre-starter and starter feed by piglets in the postnatal period, after weaning and during rearing

Parameters	Groups	Periods of experiment		
		5–28 days	29–43 days	44–80 days
Compound feed	C	0.32 ± 0.07^{a}	4.44 ± 0.07^{a}	34.24 ± 3.15^{a}
quantity for the	D1	0.40 ± 0.06^{b}	3.69 ± 0.05^{b}	32.88 ± 2.35^{a}
period, kg	D2	0.54 ± 0.04^{c}	5.22 ± 1.31^{a}	29.42 ± 1.15^{b}

Note. See Table 2.

The nature of the changes in feed intake depended on the age period (Table 6). At the early stage (5–28 days), feed intake in the experimental groups was higher than in the control group – by 24.4% in the probiotic group and by 68.3% in the postbiotic group ($P < 0.05$), which is consistent with the increased growth rates. Subsequently, this trend changed: During the 43–80-day period, feed intake was lower by 5.3% in the probiotic group and by 13.7% in the postbiotic group ($P < 0.05$), compared with the control.

Table 6
Feed conversion rates in different periods of piglet growth with the use of the studied additives (kg feed/kg gain)

Groups	43 day	80 day
Control	1.20 ± 0.06^{a}	2.01 ± 0.30^{a}
D 1	1.10 ± 0.05^{a}	1.94 ± 0.32^{a}
D 2	1.34 ± 0.29^{a}	1.59 ± 0.24^{a}

Note. See Table 2.

Feed conversion in the final stage was lower in the experimental groups (by 3.5% in the probiotic group and by 20.9% in the postbiotic group) but no statistically significant differences were found, indicating that there was no clear difference in this parameter.

Discussion

The intensive use of antibiotics as growth promoters has made it necessary to seek alternative approaches to maintaining animal health and productivity. In this context, probiotic and postbiotic feed additives are considered one of the most promising trends, as their action is linked not only to their effect on the microbiota but also to the regulation of metabolic processes in the body. At the same time, the efficacy of such additives depends to a large extent on their form, composition, and the ability to realize their biological potential under specific physiological conditions.

The results obtained showed that the effect of the researched additives depends significantly on their form. The probiotic feed additive based on the yeast strain *K. marxianus* (D1) produced a predominantly short-term response in the animals, particularly in the early postweaning period, whereas the postbiotic additive (a hydrolysate of yeast cells from the same strain [D2]) was accompanied by more stable changes in growth parameters, protein metabolism, and health status throughout the entire rearing period. The differences between these forms were not only quantitative but also qualitative in nature, suggesting different mechanisms of action.

It is widely recognized that probiotics are capable of modulating the gut microbiota, altering the nature of fermentation and improving the nutrient utilization (Krehbiel et al., 2003; Arowolo & He, 2018; Elghandour et al., 2024). At the same time, their efficacy depends largely on the survival of microorganisms in the gastrointestinal tract, which is particularly critical in young piglets. This explains the more pronounced effect of the probiotic additive during the early stage, which was manifested in a reduction in the diarrhea incidence and improved growth parameters, but subsequently tended to diminish.

At the same time, the results allow us to define the role of the probiotic form in the study more clearly. Its effect was most notable during the critical period following weaning, when the development of the gut microbiota is not yet complete. Under these conditions, the probiotic supplement contributed to the rapid stabilization of the microbial environment, the inhibition of pathogen growth, and the normalization of digestion. Subsequently, as the microbiota stabilized, its effect diminished, which explains the less significant differences in the later stages of rearing.

Unlike probiotics, postbiotics contain ready-made biologically active components (peptides, free amino acids, β-glucans, mannans, vitamins, and yeast metabolites), which do not require colonization of the gut to exert their effect. As a result, its action is less dependent on the conditions of the gastrointestinal tract and is more stable over time. This explains why positive changes were maintained throughout the entire rearing period in group D2.

A comparison of the two forms clearly highlights the fundamental difference between them. A probiotic additive exerts its effect primarily by altering the gut microbiota and is most effective during the early stages of animal development. By contrast, the postbiotic form acts directly, by incorporating its components into the body's metabolic processes, ensuring a longer-lasting and more consistent effect. While the probiotic form did not maintain its effect in the later stages of rearing, the postbiotic form demonstrated its stability, indicating a fundamentally different nature of their action.

Yeast-based bioproducts, as a source of bioactive compounds, have long been regarded as an effective tool for improving animal productivity (Nisbet et al., 1991; Girard et al., 1994; Elghandour et al., 2020). Of particular interest is *Kluyveromyces marxianus*, which is characterized by high metabolic activity and the ability to synthesize a wide range of enzymes (Koukoumaki et al., 2024). In this context, it is important to note that the same biological substrate can exhibit different effects depending on the form of application.

The improvement in protein metabolism observed in the study indicates the activation of synthetic processes in the body. The more pronounced changes in group D2 reflect higher availability of amino acids and peptides, which is supported by the data from other studies on hydrolyzed yeast, demonstrating improvements in growth performance, gut health, and immune response in piglets (Berto et al., 2020; Boontiam et al., 2022). In the case of the probiotic form, such changes were also observed, but were less persistent in nature.

The increase in the globulin levels and the reduction in the diarrhea incidence are consistent with the notion that yeast cell components have immunomodulatory properties. Beta-glucans and mannan-oligosaccharides are capable of strengthening the intestinal barrier function and modulating the immune response, reducing the level of inflammatory processes and increasing resistance to infections (Collier et al., 2011; Su et al., 2022), which directly limits the translocation of pathogens and clinically manifests as a reduction in the diarrhea incidence. This explains the more pronounced and stable effect of the postbiotic form compared with the probiotic form.

The reduction in the transaminase activity in the experimental groups indicates a stabilization of metabolic processes and the absence of functional overload on the body. This may suggest a reduction in the metabolic load on the liver and more effective adaptation of the animals to the rearing conditions. Furthermore, the more consistent trend in these indicators in group D2 further confirms its more stable effect.

The improvement in live weight gain and feed conversion efficiency is consistent with findings from other studies, where the use of hydrolyzed yeast was associated with improved growth performance and gut health (Molist et al., 2014; Boontiam et al., 2022). In our case, these effects manifested differently, depending on the form of the additive: The probiotic form produced more notable effect at the early stage, while the postbiotic form ensured its persistence thereafter.

However, the results of using yeast-based bioproducts are not conclusive. Some studies have shown that their efficacy depends on housing conditions, diet composition, and dosage, and that the effects observed may be inconsistent (Kiros et al., 2019). The reduction in the transaminase activity in the experimental groups, which was more pronounced in D2, indicates a stabilization of metabolic processes and is consistent with the data obtained regarding the improvement in the overall functional state of the organism. This suggests that the effect of such additive is largely determined not only by their composition but also by the conditions of use. Overall, the data obtained indicate that the use of yeast products based on *K. marxianus* is an effective means for improving piglet performance; however, the nature of this effect is determined by the form of the supplement. Thus, the probiotic form provides a rapid adaptive response in the early stages, while the postbiotic form provides more stable metabolic support to the organism throughout the entire rearing period.

Conclusions

The study was designed to investigate the effect of probiotic and postbiotic feed additives on the performance, health and physiological parameters of piglets during the early stages of development – from 5 to 80 days of age.

The use of the probiotic strain *K. marxianus* contributed to the improved performance parameters in the early stages of rearing, as well as increased feed efficiency. The most pronounced effect was observed during the period up to 43 days of age. At the same time, the use of hydrolyzed *K. marxianus* yeast proved to be most effective during the postweaning period and until the end of the experiment. This may be due to the presence of biologically active components of the cell wall and low-molecular-weight metabolites in the hydrolysate, which are capable of positively influencing the functional state of the digestive system and the gut microbiota.

The use of the researched additives had no significant effect on the total protein levels, its fractions, or the activity of transferases in the animals' blood. At the same time, there was a tendency toward an improvement in protein metabolism and the maintenance of physiologically optimal levels of enzyme activity, indicating that the additive had no adverse effect on the animals' metabolic status.

Thus, the results of the study confirm the potential for using *K. marxianus*-based products as functional feed components in the feeding of young piglets.

The authors state that they have no conflict of interests.

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