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REVIEW

Advances in the use of active yeast in raising chickens

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Abstract

The broiler industry supplies quality protein, which is in constant development. It seeks productive strategies that improve production, health, growth, and survival and reduce the poultry industry's diseases, stress, and long-term environmental impact. Broiler chickens are exposed to numerous microorganisms that alter production, and this is an opportunity for yeasts to promote the growth of organisms, stimulate the immune system, improve health, promote changes in intestinal structure, and inhibit pathogens. This review summarizes the current knowledge and effect of active yeast species on raising chickens, nutrition, immunity, digestibility, changes in intestinal structure, and pathogens on those organisms. Due to their nutritional value, active yeasts are used as natural and alternative ingredients in broiler chickens. They are a source of b-glucans, chitin, nucleic acids, mannan-oligosaccharides, b-carotene, and vitamins. Enzymes they produce improve intestinal maturity and digestion. The immune and antioxidant properties of yeasts play an essential role as probiotics and immunostimulants to enhance the resistance of broilers against common viral and bacterial diseases. Bioactive products generated by active yeasts can improve intestinal microbiota and positively alter the immune response, phagocytosis, encapsulation, etc. Different active yeast species and strains have been used and have generated exciting results. They are popular as beneficial candidates for nutrition by maintaining broiler chickens' health's and well-being conditions. Future studies must understand the functioning and effect of species and strains on broiler chickens in their different processes, the use of new research tools (proteomics, radioisotopes, real-time molecular biology, etc.) can facilitate these studies.

Keywords: broiler environment; poultry industry; raising conditions; yeast; animal welfare.

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1. Introduction

Modern broiler breeds are the result of artificial selection for commercial purposes. Broilers, in different breeds, are an essential source of high-quality protein for consumption that is constantly growing worldwide (Dixon et al., 2022). The size of broilers for consumption (4 or more weeks) may vary depending on the breed and production area (Asia, Europe, and North America). However, the industry is constantly affected by infectious diseases (viruses and bacteria) that generate significant losses in production (Bagust, 2013; Dixon et al., 2022; FAO, 2023).

The rapid and uncontrolled growth of pathogens in broiler chickens and the excessive use of antibiotics as prophylactics have generated the emergence of several resistant pathogens that cause acute and chronic diseases that reduce the development and sustainability of the industry worldwide (Haldar et al., 2011; Fanelli et al., 2015; Ahiwe et al., 2021). Antibiotics improve food safety and animal health by reducing or eliminating pathogens. However, due to the side effects of antibiotics (accumulation, resistance, etc.), these products become a threat that must be eliminated, reduced, or replaced with new products or alternative strategies that benefit production and the environment (Haldar et al., 2011; Ahiwe et al., 2021; Fathima et al., 2023). Alternative methods of disease prevention have been designed via antioxidant systems, bioremediation, genetics, immunostimulants, nutrition, probiotics, prebiotics, symbiotics, etc. (Haldar et al., 2011; Khan & Naz, 2013; Sapsuha et al., 2021).

Yeast is one of the first domesticated organisms, of which 1% of the yeast species are known (Fell, 2001;

Patterson et al., 2023). These have demonstrated the potential to produce bioactive products (glucans, glutathione, enzymes, phytase, vitamins, etc.) with application in the chemical, cosmetic, food, pharmaceutical, animal protection, and reduction of adverse environmental effects industries (Cheng et al., 2014; Zaky et al., 2014; Sarkar & Bhaskara, 2016; Fathima et al., 2023; Patterson et al., 2023). Yeast (whole, parts, molecules, extracts) are a popular product in animal production as a food supplement, source of amino acids, and proteins. They participate in the production of B complex vitamins, digestive enzymes, stimulation of the immunity of the intestinal mucosa, greater protection against toxins produced by pathogenic microorganisms, and a greater number of anaerobic bacteria that reduce harmful gases. These generate positive effects on the growth and immunity of the broiler chicken (Saied et al., 2011; Adebiyi et al., 2012).

Active or living yeasts, like other cells, have a complex biochemical system where different internal metabolic systems interact. It is necessary to document its effect on monogastric better (Gao et al., 2008), its relationship with systems related to dispersion mechanisms, the interaction between cells (inter or intraspecies), cellular communication, and the production of extracellular molecules in response to chemical and physical stimuli from the external environment and the environment, inside the cell. Cells also have multiple metabolic mechanisms for defense, adhesion, colonization, etc. This review summarizes the current knowledge of the main yeast strains used as probiotics, feed additives, and immunostimulants to reduce feed costs and improve growth and survival in broiler production. The information provided is focused on works that directly used active yeast, showing its effects on digestion, growth parameters, immune system, meat quality, metabolism, and physiology.

2. Yeast used in broilers chicken

Broiler chickens interact with a high and diverse range of environmental and microorganisms, which could play a vital role in their growth, survival, and welfare. Yeasts are microorganisms usually found in the environment and areas and organisms under raising, documenting their role in the health and nutrition of broiler chickens. These microorganisms have been used live (active) as ingredients or food supplements to feed broilers, generating multiple beneficial effects. Some yeast genera (*Candida* sp., *Cyberlindnera* sp., *Debaryomyces* sp., *Kluyveromyces* sp., *Phaffia* sp., *Rhodotorula* sp., *Torulaspora* sp., *Saccharomyces* sp., *Yarrowia* sp., and *Zygosaccharomyces*) are part of the intestinal flora of the broiler and have shown their application in the cultivation of this organism (in their different breeds)(Gao et al., 2008; Haldar et al. 2011; Cafarchia et al., 2018; Laubscher et al., 2020; Ahiwe et al., 2021; Bilal et al., 2021; Grabež et al., 2022; Kim et al., 2022; Liu et al., 2022; Dedousi et al., 2023). A better understanding of the recent use and modes of action of active yeast in broilers is present in Tables 1-5.

2.1. *Candida*. This group of yeasts is from the class Saccharomycetes, division Ascomycota, and at least 100 species are described. This yeast has about 200 species, many of which are commensals, harmless endosymbionts, or opportunistic pathogens. This yeast is part of the bacterial flora on the surface of the mucous membranes, mainly those of the gastrointestinal tract or the skin. They are widely distributed in nature and can grow in different environments and temperatures. Yeast cells are globose, ellipsoidal, cylindrical, or elongated in shape and occasionally ogival and triangular during asexual reproduction (Hommel, 2014). The Candida yeast that has been used as an ingredient (active cell) in research works associated with broiler chickens is *Candida utilis* (Rodríguez et al., 2013; Wang et al., 2020) (Table 1, 3, 4).

2.2. *Cyberlindnera*. Previously called Lindnera, it shows an asexual reproduction, budding is multilateral on a narrow base, and their cells are spherical, oval, or elongated. In sexual reproduction, asci may be conjugated, showing conjugation between cells. Also, some species are heterothallic (Kurtzman, 2011). This author shows that there are several species of this yeast (*Cyberlindnera americana*, *Cy. amylophila*, *Cy. bimundalis*, *Cy. euphorbiae*, *Cy. euphorbiiphila*, *C. fabianii*, *C. jadinii*, *Cy. japónica*, *etc.*).

2.3. *Debaryomyces*. They are from the class Saccharomyces, division Ascomycota, they are commonly found in the environment, they are widely used in the food industry, and at least 30 species have been described. Their cells are globose, ovoid, or lenticular in shape during asexual reproduction, which is of the multilateral germination type (Wrent et al., 2014). Genetic studies show different defined species; however, some of them have high genetic heterogeneity (*Debaryomyces artagaveytiae*, *D. carsonii*, *D. castellii*, *D. coudertii*, *D. etchellsii*, *D. globularis*, *D. hansenii*, etc.)(Wrent et al., 2014).

Table 1
Effect of active yeast on growth parameters of broilers chicken

Yeast	Broilers chicks	Doses	Use	References
Candida utilis	Cornish x White Plymouth Rock, hybrid HE21 (both sexes, 1-day-old)	10-30%	The 30% dose shows a significantly higher value is observed in total feed intake (FI), feed conversion ratio (FCR), and lower live weight, and live weight gain.	Rodríguez et al., 2013
Debaryomyces hansenii	Ross 308 (male and female 1-day-old)	5×10^6 CFU kg feed^{-1}	Body weight, feed consumption (FC), weight gain, and FCR were similar controls.	Liu et al., 2022
Kluyveromyces marxianus	Arbor Acre (1-day-old female)	0.25-2.5 g kg^{-1} (2.0×10^{10} CFU g^{-1})	A significant reduction in the FCR compared to the control (2-2.5 g kg^{-1}).	Wang et al., 2017a
K. marxianus	Ross-308 (1-day-old)	(4.125×10^6 CFU 100 mL^{-1})	Significant increase in body weight, lower FC and better FCR	Khalifa et al., 2024
K. marxianus	Ross308 (1-day-old)	0.002-0.005%	Significantly reduces mortality	Rassmidatta et al., 2024
Phaffia rhodozyma	Ross broilers (14-day-old female)	10-20 mg kg^{-1}	Higher body weight gain, feed intake, and feed efficiency compared to the control group.	Perenlei et al., 2014
Saccharomyces boulardii	Sanhuang (200-day-old)	10^8 CFU kg^{-1}	Significant increase in body weight compared to the control group.	Sun et al., 2017
S. cerevisiae	Broiler chick (180-day-old)	0.2%	Significant increase in body weight.	Churchill et al., 2000
S. cerevisiae	Ross breed (male, 1-day-old)	0.5%	Used in growth parameter generating a gain in body weight compared to control.	Zhang et al., 2005
S. cerevisiae	Ross (male 240-day-old)	0.5-2%	The use of 1.5% yeast in the feed significantly increases body weight gain and FI and shows a significantly better FCR.	Paryad & Mahmoudi, 2008
S. cerevisiae	Arbor Acres (male, 1-day-old)	2.5 g kg^{-1} diet	Significant increase in average daily weight gain and FCR. Significantly increased the digestibility of calcium and phosphorus but did not affect protein and energy retention digestibility.	Gao et al., 2008
S. cerevisiae	Ross 308	0.5-2% (8×10^9 CFU g^{-1})	Significant results in FI, live weight, and final weight gain in organisms fed yeast diets.	Hosseini, 2011
S. cerevisiae	Cobb (1-day-old)	1 g kg^{-1} diet	Significantly improves final weight, daily and total weight gain, and FCR.	Haldar et al. 2011
S. cerevisiae	Cobb (1-day-old, 45 g)	0.5 g Live yeast kg diet^{-1}	Significant decrease in FI, FCR, and mortality. Significant increase in final post-slaughter weight.	Iraqi & Fayed, 2012
S. cerevisiae	hybrid Hubbard (1-day-old)	0.25 mL (4.12×10^6 CFU 100 mL^{-1})	Significantly positive effect on body weight gain at 4th week of age compared with the control.	Aluwong et al., 2013
S. cerevisiae	Arbor Acres (1-day-old, 40 g)	3%	Significantly improved body weight gain and FCR.	Tabidi et al., 2013
Saccharomyces cerevisiae	Hubbard (1-day-old, 45 g)	0-3%	Better values in final body weight, weight gain, FI, FCR, and mortality.	Eltazi et al., 2014
S. cerevisiae	Aber acer (unsexed 1-day-old, 45 g)	0.1-0.3%	0.3% use of dry yeast had significantly higher body weight gain and the best FCR compared to control.	Hana et al., 2015
S. cerevisiae	Arbor Acres (1-day-old male)	0.5 g kg^{-1} (1.0×10^{10} CFU g^{-1})	Significantly reduces the FCR.	Wang et al., 2016b
S. cerevisiae	Cobb 400 (288-day-old)	0.1-0.2%	Significant values in body weight gain, and feed efficiency.	Shankar et al., 2017
S. cerevisiae	Cobb 500 (unsexed, 165-day-old)	0.5-3%	A positive significant difference is observed in the total weight gain and the FCR.	Lawrence-Azua et al., 2018
S. cerevisiae	Cobb (1-day-old, 43 g)	0.2%	Significantly improved live body weight, live body weight gain, and FCR.	Mousa, 2018
S. cerevisiae	Cobb (42 g)	2.5%	Significant values in final weight, total weight gain, daily weight gain, FCR, FC, and FI compared to control.	Mulatu et al., 2019
S. cerevisiae	Arbor Acres (1-day-old male, 45.2 ± 0.46 g)	0.5-1 g kg^{-1} (10^{10} CFU g^{-1})	A significant increase in final body weight and mean daily weight gain is observed at the highest dose of yeast.	He et al., 2022
S. cerevisiae	Hubbard (1-day-old)	1.5 g kg^{-1}	Weight gain, FC, and FCR improved significantly with a diet containing yeast.	Rafique et al., 2020
S. cerevisiae	Arbor Acres (unsexed 1-day-old)	0.04% kg feed^{-1} (1.2×10^{10} active yeast g^{-1})	Significant improvement in growth rate and digestibility of organic and apparent matter detected in the ashes.	Attia et al., 2020

S. cerevisiae	Broiler chicks (4 we old 0.89 kg)	0.7-1.7 g kg of basal diet^{-1}	Significant values in final body weight, total body weight gain, daily weight gain, and FCR.	Osita et al., 2020
S. cerevisiae	Arbor Acres (male 1-day-old, 45.23 g)	1 g kg^{-1} (10^{10} CFU g^{-1})	The final body weight was significantly higher compared to the control.	He et al., 2021
S. cerevisiae	Cobb 500 (male 1-day-old)	0.1% (10^{10} live yeast cells, 52 g)	A significant difference is observed in final body weight, body weight gain, FI, and FCR.	El-Manawey et al., 2021
S. cerevisiae	Mixed-sex (45.10 g)	1 g kg^{-1} diet	Significantly increased daily weight.	Kim et al., 2022
S. cerevisiae	Broiler chicks	2%	Significant result in FI, and body weight.	Gul & Alsayeqh, 2023

2.4. ***Kluyveromyces***. This is a member of the ascomycetous family Saccharomycetaceae. The molecular studies revealed there are approximately six species (*Kluyveromyces aestuarii*, *K. drosophilarum*, *K. lactis*, *K. marxianus*, *K. nonfermentans*, and *K. wickerhamii*). It has a worldwide distribution and grows in different environments, this changes its morphological, physiological, and molecular characteristics, which complicates its identification. The best-known species in the industry are *K. lactis* and *K. marxianus* for their relationship in the ripening of cheeses, yogurt, etc. It is an attractive commercial yeast species because it has higher growth rate, metabolic functions, and high mannan content in the cell wall than *Saccharomyces cerevisiae* (Belloch et al., 2011; Wang et al., 2017a).

2.5. ***Phaffia***. This is an orange color Deuteromycotina yeast (Blastomycetes) genus. It ferments glucose and other sugars to produce carotenoids that give color to the yeast, with astaxanthin being the main carotenoid produced. The yeasts have a red-orange color in their basidia. This yeast and its pigments are used as an additive in animal feed to enhance the color of the eggs and meat of terrestrial and aquatic organisms, and they are also important natural antioxidants. The following species are known: *Phaffia aurantiaca*, *P. australis*, *P. brasiliana*, *P. rhodozyma*, and *P. tasmanica*. Some recent publications indicate *P. rhodozyma* as a yeast species with the potential to be used generating interesting results in growth (Perenlei et al., 2014).

2.6. ***Saccharomyces***. It is the most widely used yeast in broilers (Table 1-5), it is also the most widely used yeast in different biotechnological and fermentation processes worldwide, such as the production of beer, wine, and bread, and it is the first eukaryotic cell whose genome was sequenced (Alsammar & Delneri, 2020; Ahiwe et al., 2021). They are from the class Saccharomyces, division Ascomycota, which reproduces by budding, presenting a haploid and diploid life cycle. Genetic studies indicate the existence of eight well-defined species (*Saccharomyces arboricolo*, *S. cerevisiae*, *S. eudayanus*, *S. jurei*, *S. kudiavzevii*, *S. mikatae*, *S. paradonus*, and *S. uvarum*) (Alsammar & Delneri, 2020).

2.7. ***Yarrowia***. They are from the class *Saccharomyces*, division Ascomycota, which has asexual growth by multilateral budding. There is only the species *Yarrowia lipolytica*; its cells have a spherical, ellipsoidal, or elongated shape, found alone, in pairs, or in small groups. Also, it has dimorphic characteristics, pseudomycelium, and branching can be observed (Sutherland et al., 2014). Patsios et al. (2020) show that *Y. lipolytica* is detected in food products such as meat, fish, dairy products, etc., and can grow in different agricultural by-products with high levels of fatty acids. This yeast is used in terrestrial and aquatic organisms, generating positive effects on their nutrition since it stores essential fatty acids intracellularly or lipid bodies (≤ 20%) and has a low content of nucleic acids that increases the palatability of diets. It also secretes heterologous proteins, has a high lysine content, generates enzymes that increase animal digestion (esterases, lipases, phosphatases, and proteases), and is a large producer of citric acid (Mirbagheri et al., 2012; Patsios et al. 2020; Guardiola et al., 2021).

3. Yeast effect on broilers chicken

The increase in the consumption of products of animal origin is estimated in the following decades, with an annual consumption of 25.5 to 37 kg per person in developed countries and 88 to 100 kg per person in industrialized countries by 2030 (FAO, 2003; Patsios et al., 2020). The livestock sector is constantly growing because of population growth, economic income, and lifestyle and dietary habits changes. Satisfying this constant growth and maintaining the natural resource base (soil, water, air, and biodiversity) are significant challenges facing global livestock today. Poultry production is significant due to the short time in its production cycle, the quality of its meat, and low cost for the consumer. This increase in production has been strengthened by moving from extensive to intensive integrated activity (market, consumers, cost). This phenomenon has increased competition for ingredients for poultry nutrition, increasing the environmental and public health risks of this industry as it is located near urban areas (FAO, 2003, 2023). Feed represents a high cost in the production of broiler chickens (>50%), and efficiency in the use of ingredients and additives that favor its use is significant in production (FAO, 2003). Yeasts are microorganisms that have been used as animal feed supplements. Its application is greatly facilitated by its high acceptability and availability; several species and/or yeast strains are native to various food products (meat, fish, dairy products, etc.) (Patsios et al., 2020).

Figure 1 shows the main areas of study where the studies evaluated in the present research (2000-2023) have focused on the use of active yeasts in broiler chicken, where the areas of growth parameters (weigh, feed conversion rate, survival, feed intake, etc.), blood parameters (cell number, immunology, immunostimulant, blood chemistry, etc.), microorganisms present in broilers, size of chicken organs and tissues, intestine characteristics, and behavior of the birds were the most studied.

3.1. Yeast effect on growth parameters of broilers chicken

Growth parameters are an important indicator of the effectiveness of the application of an ingredient in the diet of organisms and are a starting point to quantify the future environmental impact of the poultry sector (Cheng et al., 2014). The growth of organisms is directly related to the balance of nutrients in the diet and the ingredients that make it up. Protein is the most expensive and limiting nutrient in the production of animal feed, The decrease in this nutrient or its quality results in poor growth, diseases, etc. (Adebiyi et al., 2012; Rafique et al., 2020; Patterson et al., 2023).

The use of alternative protein ingredients or supplements is necessary to strengthen the animal feed supply chain, also reducing the impact on the environment. This has allowed the use of new protein sources (insect meal, micro and macroalgae, microorganisms, byproducts of the food industry, etc.) in animal feed (Patterson et al., 2023).

One of the poultry industry's challenges is maintaining productive efficiency through the proper use of feed and its ingredients (Paryad & Mahmoudi, 2008). In recent decades, the production of some traditional ingredients used in animal feed has decreased, allowing the use of alternative ingredients as possible substitutes. Yeast has been used as an ingredient in the diets of horses, cows, aquatic organisms, etc., and is successfully used in poultry feed as a partial replacement for the traditional protein source (Rameshwari & Karthikeyan, 2005; Rodríguez et al., 2013). Yeasts have been used in diets for broiler breeding due to their nutritional value (proteins, lipids, vitamins, minerals, etc.) and some bioactive compounds (amino acids, β-glucans, chitin, oligosaccharides, nucleic acids, etc.) promoting feed efficiency and improving overall performance (Paryad & Mahmoudi, 2008; Morales-López et al., 2009; Saied et al., 2011; Bilal et al., 2021). Different types of active yeasts (Table 1) and their extracts have been used in broiler-raising diets at different levels (0.1 - 30% or 0.1 - 5 g kg^{-1}).

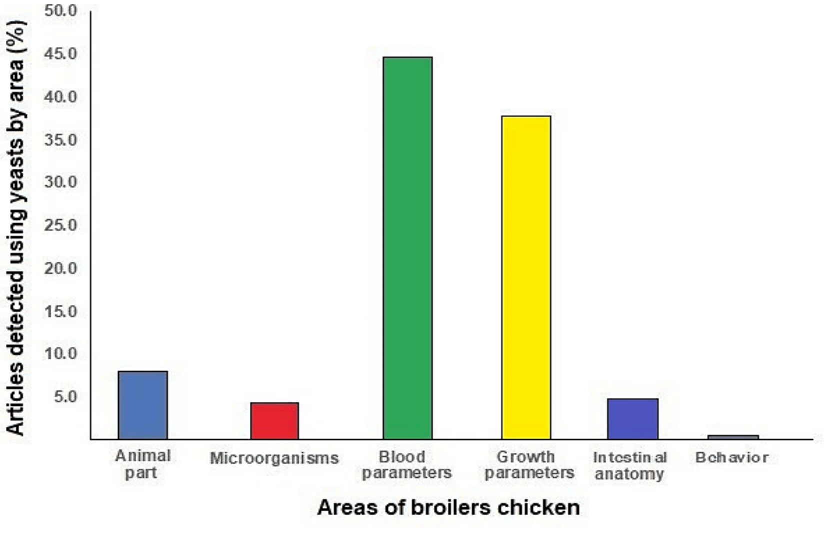

Figure 1. The main areas of study in the articles detected the use of active yeast in broilers chicken from 2000-2024.

In addition, Figure 2A shows the subject of studies associated with the area of growth parameters, where 50% of the works focused on evaluating growth, 20% on conversion factor (FCR), 16% on consumption, 7% on digestibility, and almost 3% on mortality.

Rodríguez et al. (2013) and Perenlei et al. (2014) used *Candida utilis* and *Phaffia rhodozyma* at different doses, detecting significant improvements in live weight, weight gain, FCR, and feed intake at the highest dose. Wang et al. (2017a) and Liu et al. (2022) used *Kluyveromyces marxianus* and *Debaryomyces hansenii* at different doses, improving the feed conversion ratio, respectively. Table 1 shows that *Saccharomyces cerevisiae* is the most widely used yeast in diets as a growth promoter for broilers, which has been used in different broiler breeds and hybrids by supplying it in their feed or drinking water. This yeast has been applied at doses of 0.04 - 3%, 0.5 - 2.5 g kg^{-1} diet, and 10^6 - 10^{10} CFU g^{-1} with positive and significant effects on different growth parameters. Haldar et al. (2011) and Mousa (2018) show average daily gain and FCR when supplying *S. cerevisiae* (1 g kg^{-1}) or 0.2% at 35 d post-application, respectively. Gao et al. (2008) used active *S. cerevisiae* yeast at a dose of 2.5 g kg^{-1} diet, significantly improving daily weight gain, and FCR: increasing the digestibility of calcium and phosphorus. Similar results were obtained by Hana et al. (2015), El-Manawey et al. (2021) and He et al. (2021). Attia et al. (2020) obtained similar results with the digestibility of organic and apparent matter detected in the ashes. Sun et al. (2017) and Bilal et al. (2021) used *S. boulardii*, revealing significant results in body weight gain, particularly during the early life of broiler chickens. Iraqi & Fayed (2012), Aluwong et al. (2013), Tabidi et al. (2013), Eltazi et al. (2014), and Lawrence-Azua et al. (2018) used active *S. cerevisiae* yeast and improving weight gain, FCR, and/or reducing mortality of the organisms.

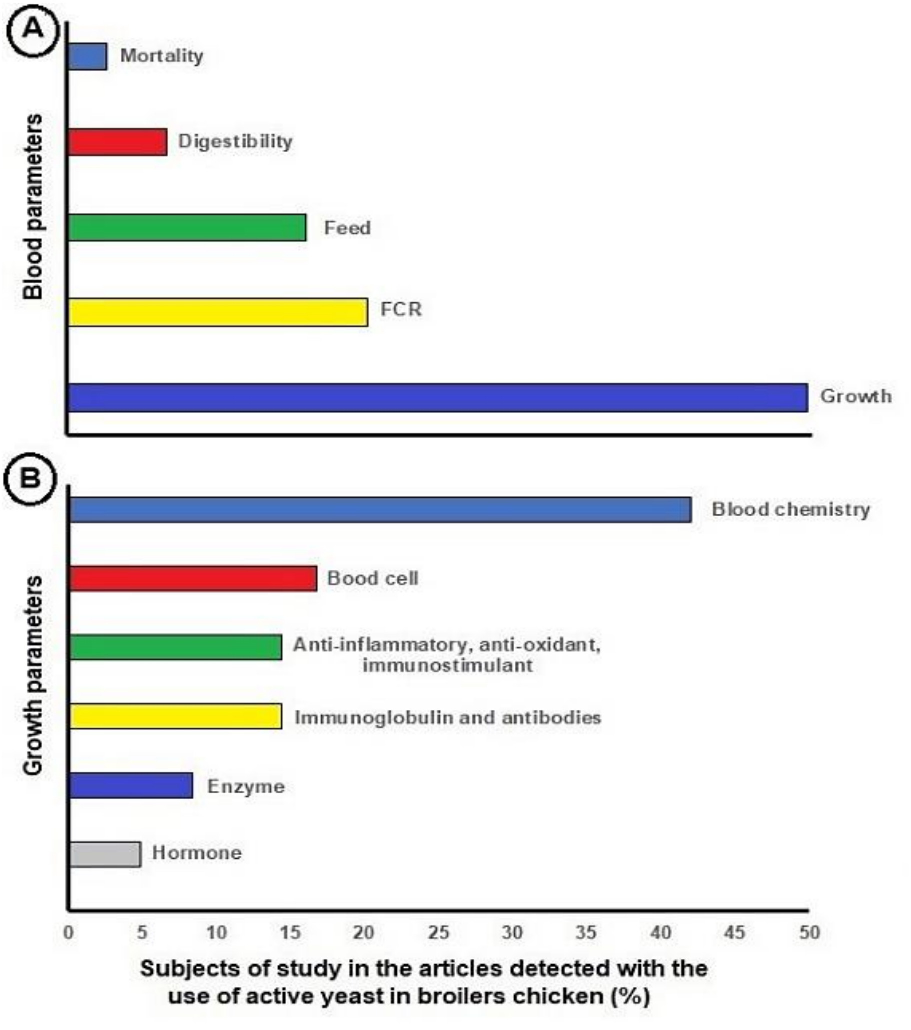

Figure 2. Subjects of study in the articles detected the use of active yeast in broilers chicken from 2000-2024.

3.2. Yeast effect on the size and meat quality of broilers chicken

Other components used to evaluate growth in broilers are the size, characteristics, and quality of the animal's meat and organs used for consumption. *Candida utilis*, *Cyberlindnera jadinii*, and *Saccharomyces cerevisiae* have been used in different breeds of broiler chickens to determine carcass parameters (Dressing, breast, legs, liver, heart, gizzard, and abdominal fat). In addition to the content of molecules such as linoleic acid, glutathione peroxidase, polyunsaturated fatty acids (PUFA), n-3 fatty acids, and PUFA/saturated fatty acids ratio, etc. (Table 2). Yeast contains α-glucan (sulfate, phosphate, carboxymethyl glucan, etc.), mannans, and some protein substances with antioxidant properties against free radicals.

Different authors show that enrichment of diets using active yeasts can significantly improve the quality of edible meat and carcass characteristics of unchallenged broiler chickens (Table 2). Mousa (2018) used active yeast and detected a significant increase in total edible parts compared to the control.

Table 2
Effect of active yeast on meat quality, carcass, organ, and tissues of broilers chicken

Yeast	Broilers chicks	Doses	Use	References
Candida utilis	White (male 7-day-old)	3 mg/kg	Significantly decreases the drip-loss rate of breast meat compared to control.	Wang et al., 2020
Cyberlindnera jadinii	Ross (male 42g)	10-30%	Carcass weight and linoleic acid in the chicken were reduced. The cold-leg meat stored showed greater browning and metallic flavor compared to the control.	Grabež et al., 2022
K. marxianus	Ross-308 (1-day-old)	(4.125×10^6 CFU 100 mL^{-1})	Higher weight on carcass weight, and spleen (%)	Khalifa et al., 2024
Phaffia rhodozyma	Ross broilers (14-day-old, female)	10-20 mg kg^{-1}	Higher percentage of total body weight in breast muscle, liver, and abdominal fat compared to the control group.	Perenlei et al., 2014
Saccharomyces cerevisiae	Ross (male (breed, 1-day-old)	0.5%	Decreases shear forces in cooked breast and thigh compared to control.	Zhang et al., 2005
S. cerevisiae	Ross (male 240-day-old)	0.5-2%	The ratio (1.5-2%) significantly improved the carcass parameters (dressing, breast, legs, liver, heart, gizzard, and abdominal fat).	Paryad & Mahmoudi, 2008
S. cerevisiae	Ross 308 (male)	2% (8×10^9 CFU g^{-1})	Loss in the percentage of liver, heart, abdominal fat, and gizzard due to yeast diets.	Hosseini, 2011
S. cerevisiae	hybrid Hubbard (1-day-old	0.25 - 0.5 mL (4.125×10^6 CFU 100 mL^{-1})	Significant increase in the weight of the drumstick, heart, gizzard, liver, lung, and thigh compared to the control group. Also, a low weight on abdominal fat.	Aluwong et al., 2013
S. cerevisiae	Arbor Acres Plus (7-day-old, 180 g)	0.5%	A significantly lower level of abdominal fat at 35-day-old compared to the control. Lower values of malondialdehyde and significantly higher values of glutathione peroxidase, polyunsaturated fatty acids (PUFA), and n-3 fatty acids. and PUFA/saturated fatty acids ratio, but the n-6/n-3 ratio decreases in the breast meat compared to the control (35 d).	Hussein & Selim, 2018
S. cerevisiae	Cobb (1-day-old, 43 g)	0.2%	Significant increase in total edible parts compared to the control.	Mousa, 2018
S. cerevisiae	Cobb (42 g)	2.5%	Significant values in the dressed carcass (g and %), eviscerated (g and %), breast meat (g), liver (g and %), heart (g and %), kidney (g and %), spleen (g), caeca (g), and small intestine (g) compared to control.	Mulatu et al., 2019
S. cerevisiae	Aber acer (unsexed 1-day-old, 45 g)	0.1-0.3%	0.3% use of dry yeast had the lowest abdominal fat and highest carcass yield compared to the control.	Hana et al., 2015
S. cerevisiae	Arbor Acres male 1-day-old, 45.23 g)	0.5-1 g kg^{-1} (10^{10} CF g^{-1})	Body protein retention is significantly higher than the control.	He et al., 2021
S. cerevisiae	Arbor Acres (1-day-old male, 45.2 ± 0.46 g)	500-1000 mg kg^{-1} (10^{10} CFU g^{-1})	The highest dose of yeast significantly improved pH-24h and reduced serum lactate content. A significantly improved total antioxidant capacity and reduced malondialdehyde in serum and muscles.	He et al., 2022

Paryad & Mahmoudi (2008), Hosseini (2011), Mulatu et al. (2019), and Grabež et al. (2022) show that using active yeast at levels higher than 2% or 10^9 CFU g^{-1} diets can generate a reduction in the size of the tissues and in the carcass of the birds. Dedousi et al. (2023) used *Yarrowia lipolytica* observing a significant reduction in malondialdehyde values in breast and thigh meat. A higher level of monounsaturated and polyunsaturated fatty acids (PUFA), a lower level of saturated fatty acids (SFA), and a better PUFA/SFA ratio were also detected. Hana et al. (2015) show that using 0.3% dry yeast (*S. cerevisiae*) had the lowest abdominal fat and highest carcass yield compared to the control. Using *Phaffia rhodozyma* in broiler diets generated a higher percentage of body weight in the pectoral muscle, liver, and abdominal fat in experimental broilers (Perenlei et al., 2014). Grabež et al. (2022) used *Cy. Jadinii* observed that the leg meat of the bird had a more browning color when stored (4 °C) compared to the control.

Zhang et al. (2005) indicated that the antioxidant effect provided by active yeasts could favor oxidative stability in chicken meat and suggest that dietary supplementation with *S. cerevisiae* improves meat tenderness in broilers. This parameter is of great importance and influence for the consumer. He et al. (2022) used active yeast *S. cerevisiae* in broiler diets, demonstrating that the level of lactate and malondialdehyde in serum and muscles was significantly reduced. Similar results were detected by Hussein & Selim (2018), Wang et al. (2020), and Dedousi et al. (2023) using *S. cerevisiae*, *C. utilis*, and *Y. lipolytica*, respectively. Also, He et al. (2021) used active yeast and showed significantly higher body protein retention than the control. Aluwong et al. (2013) showed that the use of active *S. cerevisiae* significantly increased the weight of the heart, gizzard, liver, lung, and thigh, detecting a significant reduction in the abdominal fat of the birds. Sun et al. (2017) displayed a significant increase in the weight of the bursa of Fabricius and the thymus of Sanhuang broilers feeding with a diet with *S. boulardii* compared to the control group.

3.3. Yeast effect on immunity of broilers chicken

The blood hematological parameters analysis on broiler chickens is important because it provides information on the animal's health status.

Lawrence-Azua et al. (2018) show that when using active yeast (*Saccharomyces cerevisiae*), their hematological parameters (volume of concentrated cells, white blood cells, heterophils, monocytes, average level of eosinophils and hemoglobin corpuscular) was significantly influenced using yeast. Rafique et al. (2020) show a significant increase in hemoglobin levels and packed cell volume in broiler chickens fed with active yeast (*S. cerevisiae*). This can alter the immune response of the birds, as could also be observed with the significant variation of all the biochemical parameters of the serum, except for total proteins, globulins, and glucose. Poultry are exposed to different stressors (Bilal et al., 2021) throughout their production cycle (catching, crating, and transportation, changes in environmental temperature and humidity, contaminants, feces, feeding restriction, high population density, pathogens, pre-slaughter, vaccination, etc.) that generate immunosuppression that increases the pathogenicity and virulence of pathogens that decrease the health and growth of organisms under cultivation.

Figure 2B shows that studies associated with the immune system (immunoglobulins, antibodies, immunostimulants, etc.) are important in poultry growth. The use of yeast as an antioxidant and/or anti-stress agent, immune system activator, strengthening organism nutrition, probiotic use, and digestive and microbial system improver are some of the components used to explain how yeasts are associated with the systems of defense and health generation in chickens (Table 1-5).

Different studies have associated these microorganisms and their cellular components with the health of broilers. Some results show the link with anticoagulant proteins, agglutinins, antimicrobial peptides or AMP, encapsulation of antiapoptotic proteins, and bacteriocins. They have also been associated with antibodies, immunoglobulin (IgA, IgG, IgM) activation, free radicals, gramicidin, glutathione levels, humoral components and cells, lipoprotein, lysozymes, monostatin, nodule formation, phenol oxidase enzyme, phagocytosis, proteases, peroxide hydrogen, polymyxin, siderophores, thyrotricidin, etc. (Gao et al., 2008; Paryad & Mahmoudi, 2008; Aluwong et al., 2013; Wang et al., 2016a, 2017a, 2020; Sun et al., 2017; Lawrence-Azua et al., 2018; Mousa, 2018; Kim et al., 2022; Gul & Alsayeqh, 2023). Glutathione is a molecule widely distributed in yeast and maintains an intracellular redox environment; a higher content of this molecule increases the antioxidant capacity of the yeast. The elimination of free radicals in the body of animals depends on a non-enzymatic (Vit. C, E, and glutathione) and enzymatic (glutathione peroxidase, catalase, and superoxide dismutase) system. The activities of these enzymes in serum and tissues, as well as the GSH content in them, are indicators of the antioxidant capacity present in broiler chicken (Wang et al., 2020).

3.3. Yeast effect on immunostimulation of broilers chicken

Table 3 shows the active yeast species used (*Candida utilis*, *Saccharomyces cerevisiae*, *Yarrowia lipolytica*) to improve blood parameters or immunostimulation of broiler chickens. Immunostimulants are products that can promote and induce a strong defense response in the host. Active yeasts generate different bioproducts (carotenoids, glucans, lipids, nucleotides, polysaccharides, proteins, vitamins, etc.) that activate the immune system (innate or acquired) of organisms (Gheisari & Kholeghipour 2006; Haldar et al., 2011; Aluwong et al., 2013; Rodríguez et al., 2013; Fanelli et al., 2015; Mousa, 2018; Ahiwe et al., 2021; Sun et al., 2021). Based on previous publications, immunostimulants can increase phagocytosis of pathogens by activating phagocytic cells, increasing antibacterial and antiseptic properties of blood, and phagocytic signal recognition (Gheisari & Kholeghipour 2006; Fathima et al., 2023; Gul & Alsayeqh 2023). Broilers fed with a diet with active yeast from 0.1% up to 7.5 g kg^{-1} showed a significantly higher immune response compared to the control (Wang et al., 2016a, 2016b; Wang et al., 2017a, 2017b; El-Manawey et al., 2021; Dedousi et al., 2023; Gul & Alsayeqh 2023).

3.4. Yeast effect on immunology cells of broilers chicken

Lymphocytes are important components in blood that participate in clotting, encapsulation, nodule formation, phagocytosis, and tissue repair. In addition, they help produce adhesion molecules, ligands, agglutinins, and AMPs. Lymphocytes also have inhibitory enzymes needed for regulating the proteolytic cascade, preventing its overstimulation and the resultant tissue damage while also producing cytotoxic molecules, such as lysozyme, phosphatase, esterase, phospholipase, peroxidase, protease, etc. (Zhang et al., 2012; Lawrence-Azua et al., 2018; Fathima et al., 2023). Lymphocyte count is a parameter used to assess the immune condition of broilers whose cells have been stimulated by active yeast. Mousa (2018), Lawrence-Azua et al. (2018), and Mulatu et al. (2019) found an increase in lymphocyte count during a bioassay using *Saccharomyces cerevisiae* (Table 3).

Table 3
Effect of active yeast on blood parameters and immunology of broilers chicken

Yeast	Broilers chicks	Doses	Use	References
Candida utilis	White (male 7-day-old)	3 mg/kg	The content in whole blood and liver of broilers is significantly lower compared to the control. Glutathione levels in whole blood and liver were significantly higher. Malondialdehyde levels in serum, breast meat, and liver were significantly lower compared to the control. IgM levels were significantly higher.	Wang et al., 2020
Kluyveromyces marxianus	Arbor Acre (1-day-old female)	0.25-2.5 g kg^{-1} (2.0×10^{10} CFU g^{-1})	Increase in the serum lysozyme, IgG levels, and thymus at a yeast dose of 1.0 g kg^{-1}.	Wang et al., 2017a
K. marxianus	Ross-308 (1-day-old)	(4.125×10^{6} CFU 100 mL^{-1})	Total antioxidants capacity, catalase activity, Superoxide dismutase levels were significantly higher. Also, malondialdehyde value was significantly reduced compared to control group	Khalifa et al., 2024
Saccharomyces boulardii	Sanhuang (200-day-old)	10^{8} CFU kg^{-1}	A significant increase in the weight of the bursa of Fabricius and thymus compared to the control group. In addition to an increase in the value of tumor necrosis factor (TNF)-α, IL-10, transforming growth factor (TGF)-β, and secretory immunoglobulin A (sIgA), IgA+ cells in the duodenum section.	Sun et al., 2017
S. cerevisiae	Arbor Acres (male, 1-day-old)	0, 2.5, 5.0, and 7.5 g kg^{-1} diet.	Significant increase in Newcastle virus antibodies, serum lysozyme activity, and secretory IgM and IgA in the duodenum.	Gao et al., 2008
S. cerevisiae	Ross broiler (male 240-day-old)	0.5-2%	The ratio (1.5 and 2%) significantly reduced the level of plasma cholesterol and triglycerides, and significantly increased high-density lipoprotein in plasma. The ratio (1.5%) is significantly higher in total plasma protein, albumin, and globulin levels.	Paryad & Mahmoudi, 2008
S. cerevisiae	Cobb (1-day-old)	1 g kg^{-1} diet.	Significant increase in Newcastle virus antibodies (35 d). Significantly higher values were detected in phosphorus and thyroxine (T_4) and significantly lower in Cortisol. Higher values were also observed in phospholipids and triiodothyronine (T_3), and lower in insulin.	Haldar et al., 2011
S. cerevisiae	hybrid Hubbard (1-day-old)	0.25 - 0.5 mL (4.125×10^{6} CFU 100 mL^{-1})	Glutathione peroxidase activity was significantly higher compared with the control.	Aluwong et al., 2013

S. cerevisiae	Cobb (1-day-old male)	0.5 g kg^{-1} (10^{10} CFU g^{-1})	Significantly lower serum nitric oxide content (27 d) concerning the control.	Wang et al., 2016a
S. cerevisiae	Arbor Acres (1-day-old male)	0.5 g kg^{-1} (10^{10} CFU g^{-1})	Significant reduction of serum diamine oxidase and ileal myeloperoxidase levels.	Wang et al., 2016b
S. cerevisiae	Cobb (1-day-old male)	0.05% (10^{10} CFU g^{-1})	Increase in anti-Newcastle virus serum titers (21 d).	Wang et al., 2017b
S. cerevisiae	Arbor Acres Plus (7-day-old, 180 g)	0.5%	Presence of significantly higher total serum proteins, globulin, and glucose, but less total lipids and cholesterol than the control (35-day-old).	Hussein & Selim, 2018
Saccharomyces cerevisiae	Cobb (1-day-old, 43 g)	0.2%	Significant increase in anti-Newcastle virus serum titers (42 d). Significant increase in lymphocytes count, hemoglobin, red blood cell count, high cell volume, total protein, and globulin compared to control. In addition, a significant decrease in total cholesterol, total lipids, albumin, albumin to globulin ratio, alanine aminotransferase, and aspartate transaminase compared to the control.	Mousa, 2018
S. cerevisiae	Cobb 500 (unsexed, 165-day-old)	0.5-3%	The packed cell volume, lymphocytes (heterophil, monocytes, eosinophil), and mean corpuscular hemoglobin concentration were significantly influenced by the dietary treatments compared to the control.	Lawrence-Azua et al., 2018
S. cerevisiae	Cobb (42 g)	2.5%	Significant values in hemoglobin, packed cell volume, and lymphocytes cell compared to control.	Mulatu et al., 2019
S. cerevisiae	Hubbard (1-day-old)	1.5 g kg^{-1}	Significant reduces the levels of blood glucose, and cholesterol in the birds compared to control. Also, higher values of hemoglobin, and packed cell volume in the birds feeding with yeast diet than control.	Rafique et al., 2020
S. cerevisiae	Cobb 500 (male 1-day-old)	0.1% (10^{10} live yeast cells, 52 g)	The titer against sheep red blood cells and Newcastle shows a significative high value compared to control. Total protein, total albumin, total globulin, alanine transaminase, aspartate aminotransferase, alkaline phosphatase, total lipids, and total cholesterol, display a significant improvement compared to control.	El-Manawey et al., 2021
S. cerevisiae	Arbor Acres (male 1-day-old, 45.23 g)	0.5-1 g kg^{-1} (10^{10} CFU g^{-1})	Significantly higher values of antibody titers for Newcastle and bursitis compared to the control and the antibiotic group. Significantly high values in the enzyme superoxide dismutase and catalase compared to the control. Total cholesterol was significantly less than the control.	He et al., 2021
S. cerevisiae	Both-sex (45.10 g)	1 g kg^{-1} diet.	High levels of serum tumor necrosis factor (TNF-α), interleukins 1β, and 6 (IL-1β and IL-6) compared to the control.	Kim et al., 2022
S. cerevisiae	Broiler chicks	2%	Significant results in total erythrocyte count, packed cell volume, hemoglobin, total lymphocytes count, total proteins, and globulin compared to control.	Gul & Alsayeqh, 2023
Yarrowia lipolytica	Ross 308 (male 13-day-old, 274.7 g)	0-5%	Yeast doses significantly decreased the malondialdehyde values in breast and thigh meat. Yeast dose (3%) in birds presented an increased concentration of monounsaturated fatty acids and polyunsaturated fatty acids (PUFAs), decreased levels of saturated fatty acids (SFAs), a better PUFA/SFA ratio, and improved health lipid indices. A significant elevation of n-3 PUFAs was observed in the thigh meat of yeast-fed groups, compared to the control.	Dedousi et al., 2023

3.5. Yeast effect on plasma molecules of broilers chicken

Many variables, such as total plasma protein content, glucose concentration, alkaline phosphatase activity, clotting time, the release of reactive oxygen intermediates, and antibacterial peptide activity (AMPs), have been considered good health parameters after stimulation with different pathogen-associated molecular patterns (Aluwong et al., 2013).

Haldar et al. (2011) show a higher value in phospholipids, phosphorus, triiodothyronine (T3), and thyroxine (T4) and significantly lower in cortisol and insulin. Aluwong et al. (2013) detected that glucose (blood), thyroxine (T4), thyroid stimulating hormone (TSH), and cholesterol (serum lipid) concentrations were significantly lower in broiler chickens fed with diets supplemented with yeast compared to the control group. A significant reduction in blood glucose and cholesterol levels was observed when using active *Saccharomyces cerevisiae* in diets for broiler chickens (Table 3) (Rafique et al., 2020). Mousa (2018) and El-Manawey et al. (2021) used active yeast (*S. cerevisiae*) at 0.2% in the diet and detected a significant decrease in total cholesterol total lipids albumin, albumin to globulin ratio, alanine aminotransferase, and aspartate transaminase compared to the control.

Paryad & Mahmoudi (2008) used active yeast in the diet of Ross broiler chicks with a reduction of cholesterol and triglycerides and an increase of high-density lipoprotein, plasma protein, albumin, and globulin levels (Table 3). He et al. (2021) used *S. cerevisiae* at a dose of 0.5-1 g kg^{-1}, detecting a significant decrease in total cholesterol.

Lysozyme is an enzyme that damages bacterial cells by hydrolysis of (1→4)-β-linkages between N-acetylmuramic acid and N-acetyl-D-glucosamine residues in a peptidoglycan. In addition to its catalytic capacity in the bacterial cell wall, this enzyme acts as an innate opsonin, reducing the negative charge and increasing phagocytosis of bacteria (gram-negative).

Gao et al. (2008) observed that the application of active yeast (*S. cerevisiae*) in the diet increased serum lysozyme content and that phagocytes mainly secrete this enzyme as a non-specific immunological factor to break down bacterial polysaccharide walls and provide protection against infection. This suggests that more phagocytes were activated in the broilers by the application of the yeast and that this may enhance the organism's immunity.

3.6. Effect of yeast on antibiotic use in broiler chickens

Antibiotics have been used for decades as a prophylactic strategy to improve feed safety, control pathogens, and promote growth in broiler production. However, these products show side effects (resistance, contamination, persistence in tissues, etc.) that have generated a growing tendency to reduce or suspend the use of antibiotics (Haldar et al., 2011; Ahiwe et al., 2021). The excessive use of subtherapeutic doses of antibiotics generates the development of resistant microorganisms, and the animals where they were applied become a source and/or reservoir of genes and strains resistant to antibiotics. This trend has strengthened the search for viable alternatives that can replace antibiotics and antimicrobial products as growth promoters in food animal production and maintain broilers' health. An alternative is the application of active microorganisms, such as yeasts, which can increase growth, strengthen the immune system, and support the control of pathogens (Gao et al., 2008). Using yeast in the broiler diet may increase commensal microbes or decrease pathogenic bacteria in the gastrointestinal system.

Antibodies in young broilers last a few days, increasing their susceptibility to disease and justifying early vaccination. Newcastle disease is a contiguous and lethal infection whose outbreak can cause severe mortality in broilers (Haldar et al., 2011; Mousa 2018; El-Manawey et al., 2021; He et al., 2021). A viable tool to reduce the presence of diseases in broilers is using feeds, ingredients, or feed additives that improve the immune system or decrease its susceptibility to pathogens that affect production. Antibody titer responses are used to determine broilers' humoral immune status. NDV antibody titers increased linearly when the level of active yeast in the diet increased, suggesting its influence on systemic immunity or humoral (Table 4). The use of active yeast (*Saccharomyces cerevisiae* at 1 g kg^{-1}) improves the immune response of Cobb broiler against the Newcastle disease 14 days after application (Haldar et al., 2011).

Gao et al. (2008) observed increased antibodies against Newcastle virus when using active yeast (*S. cerevisiae*) and increased IgM. Similar results were observed by Wang et al. (2017b, 2020), Mousa (2018), Wang et al. (2020), El-Manawey et al. (2021), and He et al. (2021) when using *Candida utilis* or *S. cerevisiae* at a dose of 0.05, 0.2, and 0.5-1 g kg^{-1} increasing levels of IgA, IgG, and/or IgM.

The presence of IgA is often used to evaluate the immune capacity of the intestinal mucosa. This molecular antibody in the intestinal mucosa is a significant component of humoral immunity and provides passive immunoprotection against invading pathogens in the gastrointestinal tract. Scientific papers on the use of active yeast in diets for broilers linked to the immunity present in the intestinal mucosa are scarce. Gao et al. (2008) showed a higher IgA content in the duodenum when fed with active yeast (Table 5). They suggested that the yeast may stimulate the humoral immune system to produce more antibodies. Sun et al. (2017) used active *S. boulardii* in broiler diets, showing that this yeast could improve the number of IgA-positive cells and levels of sIgA secretion in the duodenum (Table 5). These antibodies are found on the surface of the intestinal mucosa and protect the intestinal microvilli and crypts from damage caused by pathogens. Decreasing pathogenic intestinal flora can increase the presence and growth of a healthier bacterial flora that aids in the digestive process of feed and nutrient absorption in broilers, increasing the growth and health of the organism.

3.7. Use of yeast glucans in broiler chickens

Broiler chickens are exposed to many environmental stressors in modern production, causing a physiological response of the organism against these factors, thus affecting average growth and production. High temperatures are a continuing problem in tropical and subtropical regions and have increased with climate change generating difficulties in using nutrients. It triggers the secretion of corticosteroids, immunosuppressants that reduce productive performance by altering the metabolism to increase the energy available to minimize the effect due to high temperature and indirectly altering intestinal microflora (Nelson et al., 2018). A component of the wall of active yeasts is glucans and mannans, which modulate health by promoting phagocytic activity and regulating the response of the innate immune system, which can play an important role in reducing diseases and improving the productive performance of organisms (Morales-López et al., 2009). Typically, the commercial yeast cell wall is composed of 30 to 60% polysaccharides (15 to 30% of β-1, 3/1, 6-glucan, and mannan sugar polymers), 15 to 30% proteins, 5 to 20% lipids, and no more than 5% of chitin (Morales-López et al., 2009). Mannan-oligosaccharide and 1,3/1,6 β-glucan are components of the active yeast cell that modulate immunity, promote the growth of intestinal microflora, and increase growth (Shashidhara & Devegowda, 2003). Glucans are glucose units linked through the b-1,6-glycosidic bond. These can bind to receptors on the surface of immune cells [lectin receptors, dectin-1, complement receptors (CR-3), toll-like receptor (TLR 2 and TLR-6) and integrins in macrophages, monocytes, neutrophils, and natural killer cells] thus stimulating the innate immune system, which then activates lymphocytes and stimulates the adaptive system, protecting broilers from diseases, also benefiting the balance of intestinal microflora, growth, and health (Ahiwe et al., 2021; Fathima et al., 2023).

Table 4
Effect of active yeast on microorganisms of broilers chicken

Yeast	Broilers chicks	Doses	Use	References
Debaryomyces hansenii	Ross 308 (male and female 1-day-old)	5×10^{6} CFU kg feed^{-1}	Significantly increase the presence of lactic acid bacteria in the cecum.	Liu et al., 2022
Kluyveromyces marxianus	Arbor Acre (1-day-old female)	0.25-2.5 g kg^{-1} (2.0×10^{10} CFU g^{-1})	The abundance of Cyanobacteria, Rickettsiales, Pseudomonadales, and *Acinetobacter junii* decreased. There is also an increased abundance of Firmicutes and *Lactobacillus* sp in the ileum.	Wang et al., 2017a
Saccharomyces cerevisiae	Cobb (1-day-old)	1 g kg^{-1} diet	Significantly lower levels of *Salmonella enteritidis* are observed in the digesta and feces, and lower in blood (35 d post-challenge, oral application at 10^{8} CFU mL^{-1}). Significantly lower levels of *Escherichia coli* are observed in the digest, and lower in blood (same condition).	Haldar et al. 2011
S. cerevisiae	Hubbard (female, 1-day-old)	10^{6} CFU g^{-1} feed	Significantly decreased the presence of *Salmonella* sp and *Campylobacter* sp on the neck, breast, cecum, and feces.	Fanelli et al., 2015
S. cerevisiae	Both sex (45.10 g)	1 g kg^{-1} diet	Lower diversity of microbiota in the ileal digest (inverse Simpson diversity), with an increase in the abundance of the Firmicutes phylum, and genus *Lactobacillus*, *Prevotella*, and *Enterococcus* compared to the control.	Kim et al., 2022

Table 5
Effect of active yeast on intestinal anatomy of broilers chicken

Yeast	Broilers chicks	Doses	Use	References
Kluyveromyces marxianus	Arbor Acre (1-day-old female)	0.25-2.5 g kg^{-1} (2.0×10^{10} CFU g^{-1})	Increase in the ratio of villus height to crypt depth of the jejunum and ileum, in addition to ileal villus height and sucrase activity, and mRNA expression in the ileum for mucin-2 and sodium-glucose.	Wang et al., 2017a
K. marxianus	Ross308 (1-day-old)	0.002-0.005%	Enhanced the villus height/crypt depth ratio compared to control	Rassmidatta et al., 2024
Saccharomyces boulardii	Sanhuang (200-day-old)	10^{8} CFU kg^{-1}	A greater height of the villus and crypt of duodenum compared to control	Sun et al., 2017
S. cerevisiae	Male broilers (Ross breed, 1-day-old)	0.5%	A greater height of the villus (ileal mucosa) is shown in comparison with the control.	Zhang et al., 2005
S. cerevisiae	Arbor Acres (male, 1-day-old)	2.5 g kg^{-1} diet	Significant increase in the height of the villus and depth of crypts in the duodenum, jejunum, and ileum.	Gao et al., 2008
S. cerevisiae	Cobb (1-day-old)	1 g kg^{-1}	Significant increase in the height of the villus in the duodenum, and significantly decreased crypt, and serosa depth in the ileum.	Haldar et al. 2011

S. cerevisiae	Arbor Acres (1-day-old male)	0.5 g kg^{-1} (10^{10} CFU g^{-1})	Significant increase in villus height and the ratio of villus height to ileal crypt depth.	Wang et al., 2016b
S. cerevisiae	Cobb (1-day-old male)	0.05-0.5% (10^{10} CFU g^{-1})	Increase the width of the jejunal, ileal microvilli, surface area of the microvilli (21 d), and villus height to crypt depth ratio, and reduce jejunal maltase activity.	Wang et al., 2017b
S. cerevisiae	Arbor Acres (unsexed 1-day-old)	0.02 and 0.04% kg feed^{-1}, 1.2×10^{10} active yeast g^{-1})	Significant effect on the length of the microvilli.	Attia et al., 2020
S. cerevisiae	Cobb 500 (45-day-old)	5 mg kg diet^{-1} (10^{7} CFU g^{-1})	The significantly greater area of the crypts of duodenum and jejunum, a smaller number of crypts mm^{-1} in the duodenum, and higher mucus production in the same tissue compared to the control	Quevedo et al., 2020
S. cerevisiae	Arbor Acres (male 1-day-old, 45.23 g)	0.5-1 g kg^{-1} (10^{10} CFU g^{-1})	The height in the microvilli of the jejunum and ileum was significantly higher compared to the control.	He et al., 2021
S. cerevisiae	Both-sex (45.10 g)	1 g kg^{-1} diet	Increase in the height and area of the duodenal microvilli and reduction in the depth of the duodenal crypts compared to the control	Kim et al., 2022

3.8. Effect of yeast on the microbiota of the digestive system

The health and growth of broilers are associated with intestinal health and microflora, this helps against pathogens and assimilates more nutrients, which promotes animal well-being and development (Roto et al., 2015). A stable microflora avoids infections in the gut by preventing colonization using bacterial antagonism, competition by attachment sites or receptors, or interfering with bacterial metabolism. The study of the intestinal microbiota generally includes only the bacteria of the cecum since it has a more favorable environment for microorganisms (lower content of enzymes, antimicrobial compounds, and bile salts); in addition to having an anatomical structure, fermentation, and production of energy metabolites that favor the broiler and its microflora. Fermentation can produce short-chain fatty acids from the starch and fiber of the food, improving digestion and release of energy for the benefit of the body (Roto et al., 2015).

3.9. Effect of yeast on the structure of the digestive system

Several authors reported improved histomorphology, nutrient digestibility, absorption, and other physiological responses when organisms are fed active yeast (Zhang et al., 2005; Gao et al., 2008; Wang et al., 2016a; Bilal et al., 2021; Sun et al., 2021). Bilal et al. (2021) show that incorporating active yeast in diets could promote and protect the structure of the villi, changing the intestinal microbial flora by altering intestinal pH. A stable value of this parameter generates adequate growth of intestinal bacterial communities, helping the digestibility and retention of nutrients that improve health and performance. Changes in the morphology of gastrointestinal microvilli and crypt may indicate the presence of toxins and pathogens that decrease the nutrient absorption surface (small microvilli) and nutritional-energetic wear due to additional cell turnover in gastric tissue. Also, a positive change in microvilli and crypts size increases the area of intentional nutrient absorption, improving growth, weight, FCR, and the antigenic response of the intestinal mucosa (Aluwong et al., 2013; Attia et al., 2020; Sun et al., 2021). Microvilli are projections on the intestinal surface that are covered with mucosa, these increase the absorption of nutrients into the bloodstream through its capillaries. The length and depth of these can change depending on the chicken's diet, stress, and digestive health. Haldar et al. (2011), Attia et al. (2020), Quevedo et al. (2020), He et al. (2021), and Kim et al. (2022) showed that broilers fed a diet supplemented with active *Saccharomyces cerevisiae* presented a significantly greater amplitude around the crypts of the duodenum and jejunum, a lower number of crypts per millimeter in the duodenum, and higher production of mucus in that tissue compared to the control group. Similar results were obtained by Sun et al. (2021) and Bilal et al. (2021) when using *S. boulardii*. Deeper crypt increases the regeneration of tissues and microvilli, which increases the absorption of nutrients, increases mucin production reduces the presence of areas affected by pathogens, and reduces the consumption of energy and nutrients used to repair this tissue (Gao et al. 2008; Quevedo et al., 2020). Wang et al. (2017b) evaluated intestinal histomorphology in broiler chickens by supplying active *S. cerevisiae*, observing an increase in the width of ileal microvilli and their surface area. Wang et al. (2017a) used *Kluyveromyces marxianus* showing an increase in the ratio between the height of the villi and the depth of the crypts of the jejunum and ileum, in addition to an increase in the height of the ileal villi and sucrase activity, expression of mRNA in the ileum for mucin-2 and sodium-glucose. Similar results are detected in Table 5, where the application of active yeasts positively altered the structure of the microvilli, crypts, and mucin in different parts of the intestine of broiler chickens.

3.10. Effect of yeast on tumor necrosis factor and interleukins

The intestinal surface is a very vulnerable site to pathogens; for this reason, this site has immunological and non-immunological properties of protection against these pathogens. For example, it has macrophages, dendritic cells, and immune response molecules between and below the surface of the epithelium. Tumor necrosis factor (TNF) is a protein from the group of cytokines released by immune system cells, generating the activation of interleukins (1-6) and is involved in secondary inflammation, apoptosis, and joint destruction. Sun et al. (2017) and Kim et al. (2022) used active *S. boulardii* and *S. cerevisiae*, respectively, showing a significant increase in the value of TNF-α and -β present in the duodenum of the organisms treated concerning control (Table 3). Interleukins (IL) are low molecular weight cytokines that function as short-distance chemical messengers in cellular communication. They are generated by leukocytes, endothelial cells, thymus, or bone marrow and function as activators, differentiators, or proliferators of the immune system cells, in addition to the secretion of antibodies, chemotaxis, and regulation of other cytokines. Sun et al. (2017) and Kim et al. (2022) use active yeasts observing an increase in IL levels (10 and 1β, 6, respectively) in the duodenal tissue (Table 3). Interleukins (IL-6), like transforming growth factor (TGF-β), stimulate the production of IgA from B cells of the lamina propria in the intestine, favoring the neutralization of antigens, preventing the binding of pathogens to the intestinal surface and increasing the homeostasis of the intestinal mucosa.

3.11. Yeast effect on digestive enzymes

Broilers have shown different digestive enzymes as carbohydrases (amylases, cellulase, chitinase, maltase), esterases, lipases, and proteases (*arylamidase*, *carboxypeptidase* A, B, *leucine aminopeptidase*, pepsin, trypsin*)* which are directly associated with feed digestion and nutrient absorption (Aluwong et al., 2013; Ahiwe et al., 2021). Using active yeast for dietary purposes might have stimulated enzyme production in broilers, contributing to development, digestion, nutrition, and health (Bilal et al., 2021). In addition, some yeasts are available to produce extracellular enzymes (amylase, deaminase, dipeptidase, lactate dehydrogenase, lipase, maltase, phospholipase, phosphatase, phytase proteinase, polypeptides, sucrose, transaminase, etc.) and bioactive substances (astaxanthin, β-carotenoid, glutathione, polyamine, trehalose, killer toxin, etc.) with potential relevance in digestive processes and nutrient absorption that provide energy to organisms (Magnoli et al., 2016; Ahiwe et al., 2021; Fathima et al. 2023). Sun et al. (2017) used active *Saccharomyces boulardii* to show that the activity of adenosine triphosphatase, gamma-glutamyl transpeptidase, lipase, and trypsin in the duodenum of the birds was significantly higher compared to the same tissue from the control group. Wang et al. (2017b) fed broilers a diet with active *S. cerevisiae* and observed a reduction of jejunal maltase activity. Those digestive enzymes play an important role in the catabolism and metabolism of the feed.

3.12. Yeast effect on disease prevention

Diseases caused by pathogens affect the organisms being raised and generate severe economic losses for the broiler industry, which are particularly susceptible to infection by coliforms and other pathogens at the beginning of their lives. The diseases cause weight reduction, food consumption, immunosuppression, and intestinal alteration. An alternative strategy for disease control is the use of active yeasts to improve broiler health and generate resistance to pathogens. Immunosuppression caused by pathogens negatively affects the poultry industry's economy. The use of antibiotics and chemotherapeutics as disease control is undesirable in broiler farms. In addition, vaccines are not effective against many bacterial diseases (Haldar et al., 2011; Ahiwe et al., 2021). Yeast has excellent nutritional content and functional properties, including a role as a probiotic and immune stimulant. Some molecules, such as β-glucan and MOS, present in active yeasts have been used to prevent adhesion and colonization of enteric pathogenic bacteria in broilers (Tiago et al., 2012; Wang et al., 2016b; Fathima et al., 2023). Those results have demonstrated the immunostimulatory activity of yeast glucans against broilers viruses, which detected the activation of genes of different immune factors, antimicrobial peptide, anti-lipopolysaccharide factor, and superoxide dismutase (SOD). The production of antioxidant enzymes such as catalase (CAT), glutathione peroxidase (GPx), and SOD in the blood of broiler chickens is needed to remove excess reactive oxygen species (ROS). An increase in the content of antioxidant molecules in broilers' blood can improve the organisms' growth and reduce disease problems (Aluwong et al., 2013; He et al., 2022). In addition, antioxidants prevent the breakdown of serum lipoproteins and contribute to the efficiency of nutrient use during the consumption of these organisms (He et al., 2022). Active yeast cells can stimulate superoxide production by neutrophils and macrophages, increasing the phagocytic capacity of these cells against pathogens. The increase in the expression of antioxidants (superoxide dismutase and glutathione) prevents damage to the structure and function of cell membranes, proteins, and nucleic acids (Wang et al., 2020). Aluwong et al. (2013) reported a significant increase in glutathione peroxidase when using active *Saccharomyces cerevisiae* in the feed of broiler chickens. He et al. (2021) used *S. cerevisiae* to detect a significantly high value in the enzyme superoxide dismutase and catalase compared to the control.

Most yeast cell wall proteins are bound to mannan oligosaccharides (MOS), which can act in the gastrointestinal tract of animals as high-affinity binding sites and compete for binding sites against pathogenic bacteria (Mannose-specific type 1 fimbria) (Shashidhara & Devegowda, 2003; Morales-López et al., 2009; Wang et al. 2016b). Avian pathogenic bacteria such as *Salmonella* sp., *Campylobacter* sp., and *E. coli* have strategies of adhesion and colonization of the intestinal mucosa based on type I fimbriae, which are reduced in the presence of active yeasts with MOS (Fathima et al., 2023). These molecules promote the growth of *Lactobacillus* sp., which neutralizes enterotoxins and inhibits the growth of some pathogens (*E. coli*, *Clostridium* sp., *Salmonella* sp., and *Streptococcus* sp.) by producing organic acids and reducing intestinal pH resulting in higher nutrient digestion and absorption. He et al. (2021) show that active yeasts can increase the production of a wide range of organic acids in the intestine of broiler chickens, generating an acidic environment that increases digestion and inhibits the growth of pathogenic bacteria. Also, Liu et al. (2022) significantly increased the presence of lactic acid bacteria in the cecum of broiler chickens by adding active *D. hansenii* to the diets showing that yeast can adhere to the epithelium that reduces the presence of pathogenic bacteria. Haldar et al. (2011) show that the number of *Salmonella* sp and *E. coli* decreased in the digest and excreta due to dietary supplementation of *S. cerevisiae*. They showed a significantly decreased presence of *Salmonella* sp. and *Campylobacter* sp. on the neck, breast, cecum, and feces. Wang et al. (2017a) used *K. marxianus* at different doses showing an abundance reduction of Cyanobacteria, Rickettsiales, Pseudomonadales, and *Acinetobacter junii*, and an increased abundance of Firmicutes and *Lactobacillus* sp in the ileum.

4. Current challenges in the use of yeast in broilers chicken

Broiler farming requires new products, techniques, and strategies to increase production and sustainability (FAO, 2023). Yeasts are microorganisms used as nutritional tools in the broiler breeding industry. Depending on the producer's objective, they have different types and applications (Zhang et al., 2005; Gao et al., 2008). However, yeasts function differently in animals depending on the species or strain of yeast used, activity or type of activity it has, whether it is alive or dead, the culture medium where it was produced, whether is it a by-product used, extraction method, and specific application considered (digestion, immunology, nutrition, pathogen control, etc.) (Hana et al., 2015; El-Manawey et al., 2021; Fathima et al., 2023). The species or breed of bird used age, health status, and environment are factors that can also alter the functioning of the yeast. The information from the present study shows that active yeasts play an interesting role in the sustainable cultivation of broilers due to their versatile effects on growth, feed efficiency, intestinal microbiota and structure, and immune response, in addition to increasing the resistance of broilers against diseases (Gao et al., 2008; Kim et al., 2022; Fathima et al., 2023).

Active yeast contains a high level of digestible proteins, amino acids, vitamins (thiamine, riboflavin, nicotinic acid, pantothenic acid, biotin, etc.), minerals (Mg and Zn), and essential elements important for the growth of broilers (Shashidhara & Devegowda, 2003; Gheisari & Kholeghipour 2006; Haldar et al., 2011; Aluwong et al., 2013; Rodríguez et al., 2013; Fanelli et al., 2015; Mousa, 2018; Sun et al., 2021). Chitin, β-glucans, and α-mannans are the main polysaccharides of yeast cell walls, which can interact to promote the elimination of pathogens through microbial antagonism and stimulation of the immune system (Morales-López et al., 2009; Fathima et al., 2023). Different positive effects on poultry production have been associated with ingesting active yeast without fully understanding the exact mechanisms of these effects (Hana et al., 2015). The positive impact of active yeast is the result of an improvement in the functioning of the immune system, use of feed and its respective nutrients, resistance to pathogens, alternative use as growth-promoting antibiotics, and beneficial changes in the intestinal structure of organisms (El-

Manawey et al., 2021). Furthermore, the literature shows no consensus on the exact dose or type/mixture of active yeast that should be administered and the feeding duration. Future research should be focused on the exact mechanism of action of these active yeast through which they produce their beneficial effects, as well as their precise dose, type, and duration of feeding.
Broiler farming is an important activity in the food sector, which has rapidly developed and intensified, but its growth has displayed an indiscriminate use of veterinary medicines, antibiotics, and chemical products as prophylactic and control measures for pathogens and diseases (FAO, 2023). This production strategy has resulted in antimicrobial resistance of different pathogens with the risk of spreading. The use of yeast and its products is a possible and viable strategy for preventing and controlling diseases to improve the quality and sustainability of broiler-raising production. Yeast research with specific active products (glucans, MOS, etc.) applies it in low levels (<1% kg broilers diet) and evaluates its effect on target areas of broilers (defense cells, immune system, muscle, etc.) (Shashidhara & Devegowda, 2003; Morales-López et al., 2009; Fathima et al., 2023).

Many studies on active yeast cells and their components have reported improved cellular and humoral responses against pathogens and as a strategy for disease prevention/control (Ahiwe et al., 2021; Kim et al., 2022). Some active yeasts directly stimulate the immune response of broilers, such as phagocytic cells, SOD activity, improvements in antibacterial properties in blood, and mediate signal recognition in cells. Another important element to study is the use of active yeasts to define the specific pathway to improve broiler health by increasing agglutinins, AMP, anti-inflammatory effect, antiapoptotic, bacteriocins, encapsulation, nodule formation and humoral components, polymyxin, siderophores, thyrotricidin, etc. (Pizzolitto et al., 2013).

It is important to increase studies of the effect of some species of active yeast on the structure of the intestine of broiler birds since the microscopic analysis of this tissue shows changes in the structure of the intestinal epithelium (larger size of microvilli and crypts), which improves the absorption of nutrients, in addition to other changes associated with intestinal microflora, anti-inflammatory factors, etc. Also, a long microvillus is correlated with improved gut health. A deeper crypt may signal a more rapid renewal of microvilli affected by inflammation caused by pathogens and their toxins (Adebiyi et al., 2012; Pizzolitto et al., 2013; Wang et al., 2017a). Repairing these damages involves using energy and nutrients that decrease the growth of broiler chickens; for this reason, intestinal health is of great importance in production. The thicker lamina propria and tunica mucosa in the ileum of the control group may be due to inflammation or reactions that occur in the intestine as a defense mechanism against the acquired bacterial load (Robinson et al., 2022). The integrity of the intestinal epithelium and its mucus production is a fundamental barrier to preventing the entry of pathogens. The mucus is composed of mucin (highly glycosylated and interconnected proteins) secreted by goblet cells; it is a barrier where commensal and pathogenic bacteria adhere and colonize. Upon entering the intestine, yeasts colonize the intestinal mucosa by adhering to mucin-binding proteins and, through competitive exclusion, compete with pathogens for the intestinal niche and nutrients (Morales-López et al., 2009).

The gastrointestinal microbiota is important throughout broilers' development, and yeasts may be part of this microbiota (Robinson et al., 2022). The microbiota contributes to the digestion of food and absorption of nutrients throughout the gastrointestinal system, and the different species of yeast have positive effects on the gastrointestinal tract by stimulating the digestive enzymatic process; this constitutes an important element to study in the future. Furthermore, evidence has shown that some yeast species/strains have interesting effects on the gastrointestinal health of broilers, which is related to improved growth, survival, and decreased stress. Future research with new generation technologies (molecular, proteomics, sequencing, real-time PCR) is important to understand the relationship of active yeasts with the microbiota and their ecosystems. It is also important to study the changes presented by the microbiota throughout the growth of broilers, as well as how raising conditions and environmental factors alter it.

Conclusions

The manuscript reveals that *Saccharomyces cerevisiae* is the main yeast actively used in diets for raising chickens. However, species such as *Candida utilis*, *Debaryomyces hansenii*, *Kluyveromyces marxianus*, *Phaffia rhodozyma*, and *Yarrowia lipolytica* are used for the same purpose and generate interesting results. The results show that not all yeast strains function similarly even when they are of the same species and that producers must consider the form of application strain and/or species selected. It is important to establish the specific area that you want to stimulate with yeast to achieve the desired result. Active yeasts are an interesting ingredient that can be used in raising chickens, providing nutritional benefits that improve the growth parameters and intestinal maturity of the birds. They can also enhance the resistance of farmed chickens against diseases by immuno-stimulation the different immune mechanisms of the birds. It is important to consider carrying out more studies on the different species of existing yeasts that can benefit the development of chicken breeding.

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Conflict of Interest Statement
Authors have no conflict of interest to declare.

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