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Application of *Saccharomyces boulardii* in feed to improve health, wellness and productivity

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ABSTRACT

One of the main pillars of human health depends on healthy nutrition. Chicken makes up a significant part of human nutrition particularly in societies experiencing economic inflation and severe disruptions to people's livelihoods. So livestock and poultry pose a crucial impact on food safety and immunity. Probiotics have acquired worldwide acceptance as a healthy ingredient for usage as a potential feed supplement to reduce food-borne diseases and confirm food hygiene from farm to fork. Feed additives containing live yeast, e.g. *Saccharomyces boulardii*, and yeast derivative products can increase feed intake and intestinal health, and improve productivity. This probiotic, non-pathogenic yeast possesses several health-beneficial properties for poultry and livestock. However, it was previously believed that yeast did not have an effective probiotic effect in chicken and poultry. In this review, the advantages of using *Saccharomyces boulardii* has been introduced as a probiotic for poultry and livestock. This comprehensive analysis explores the multifaceted applications of probiotics in animal feed from health and AMR perspectives, examining their mechanisms of action, benefits, and potential to transform sustainable animal production practices.

Keywords: Probiotics; Yeasts; *Saccharomyces boulardii*; Chickens; Meat; Health

INTRODUCTION

Livestock and poultry have been and will continue to be critical to human well-being. Nutritional scientists, microbiologists, and biochemists have placed a high priority on developing techniques to enhance poultry and livestock output over the past 30 years (1). To accomplish the aforementioned objectives, application of probiotic in the livestock and poultry feed is growing to avoid antimicrobial resistance (AMR) (2). Probiotics are live microorganisms that, when administered in sufficient doses, can improve the host's health. Probiotics are typically advised to assist in improving host defenses and speeding up the recovery from sickness. Health beneficial impacts depends on strain, dose, duration of probiotic consumption, as well as the physiological state of the host (3). Probiotics are alternative to antimicrobial growth promoters (AGPs) in livestock and poultry production systems. The poultry industry, which contributes 37% of global meat production, along with other livestock sectors, faces mounting pressure to reduce antibiotic use.

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Yeasts, either live strains or derivatives of their cell walls, are a significant source of probiotic products. The demand for natural and organic poultry and livestock products has increased, leading to greater use of probiotics. Probiotics are appealing to consumers who prefer products with minimal synthetic additives or antibiotics. Probiotics can improve meat and egg quality, which is beneficial as the global population grows (4).

The probiotic properties of *Saccharomyces cerevisiae* strains have been studied several times. Also, *S. cerevisiae* has long been a part of the diets of domestic animals. *S. cerevisiae var. boulardii* is a unicellular, low-cost active yeast with probiotic potential properties. *S. boulardii* is one of the most well-known yeasts used as a feed supplement in poultry and livestock. *S. boulardii* has been discovered to enhance intestinal health, trigger innate immunity, and collaborate with intestine-resident microorganisms to safeguard the intestinal mucosa when taken orally. *S. boulardii* with anti-inflammatory properties is enriched in nutrients and modulates the host immune response (5). According to studies, *S. boulardii* helps to break down dietary phytate to increase the nutritional value of feed (6). Furthermore, its probiotic actions facilitate intestinal transit, thereby improving host immunity, nutrient absorption, and digestion (7).

In the past ten years, a lot of research and review articles have been written regarding the use of *S. cerevisiae* for poultry and livestock. So, a review is required to indicate the potential of *S. boulardii* for use in poultry and livestock farms in various aspects. Thus, the aim of this review article is to investigate the evidence for the application of *S. boulardii* in poultry and livestock fields. This overview includes a summary of the *S. boulardii* introduction and an explanation of this yeast's health effects and mechanisms of action on poultry and livestock. Finally, the significance of this yeast on production parameters in poultry and livestock farms is described.

Search strategy. This section describes how the literature for review was chosen. ISI Web of Knowledge, Science Direct, Scopus, PubMed, and Google Scholar were explored for articles limited by language. To find additional articles, the reference lists of each article were thoroughly reviewed. Hand searches were carried out on other papers cross-indexed by authors, comments, reviews, meeting abstracts, and books. Search terms included: probiotics, *Saccharomyces boulardii*, yeast, poultry, livestock, and associated author names.

Saccharomyces boulardii. *Saccharomyces* species are known especially *S. cerevisiae* and *S. boulardii* (8). This yeast grows rapidly with a wide ability to metabolize carbohydrates (9). *S. cerevisiae* strains have been used for brewing and baking for a very long time. *S. boulardii*, a closely related strain, was found in 1920 by Henri Boulard, a French microbiologist who was in Indo-China looking for new yeast strains that could be used in fermenting processes (10).

S. boulardii has oval to spherical cells that are around 3 µm thick and 2-10 µm long. By budding and unifying, this yeast is capable of both sexual and asexual reproduction. The existence of mannose, glucose, and N-acetylglucosamine in *S. boulardii* was established by biochemical characterization up to 20%, 90%, and 2%, respectively. Its lateral cell wall consists of 1-2% total dry-weight straight chitin chains (11, 12). Because of its adaptable genome, *S. boulardii* is of particular interest. Its genome is 22% similar to the hominid genome (13).

S. boulardii has a 37°C optimal development temperature. It is resistant to low pH and can also tolerate bile acids, which makes it more competitive in the gut microenvironment, whereas other *S. cerevisiae* strains do not thrive in acidic pH levels and prefer lower temperatures (30-33°C) (14). Additionally, changes in the microbiome increase short-chain fatty acid production in both *Saccharomyces* species. Furthermore, pathogens can be eliminated directly using secretory antimicrobials. *S. boulardii* can also agglutinate pathogens (15). *S. boulardii* is an extensively utilized and researched direct-fed microbe in livestock and poultry. Based on the available data, there is no strong justification for using *Saccharomyces* in animal feed, except for the proven health benefits of *S. boulardii* in humans (9). *S. boulardii* also offers nutritional value (12). However, studies indicate that *S. boulardii* can readily accumulate harmful elements such as lead, cadmium, arsenic, and mercury (16).

The implication of *S. boulardii* for domestic animals' health. The health-promoting effects of *S. boulardii* for poultry and livestock are generally illustrated in Fig. 1. The following criteria can be used to identify the potential mechanisms behind the health benefits of *S. boulardii* as an effective probiotic in animal production:

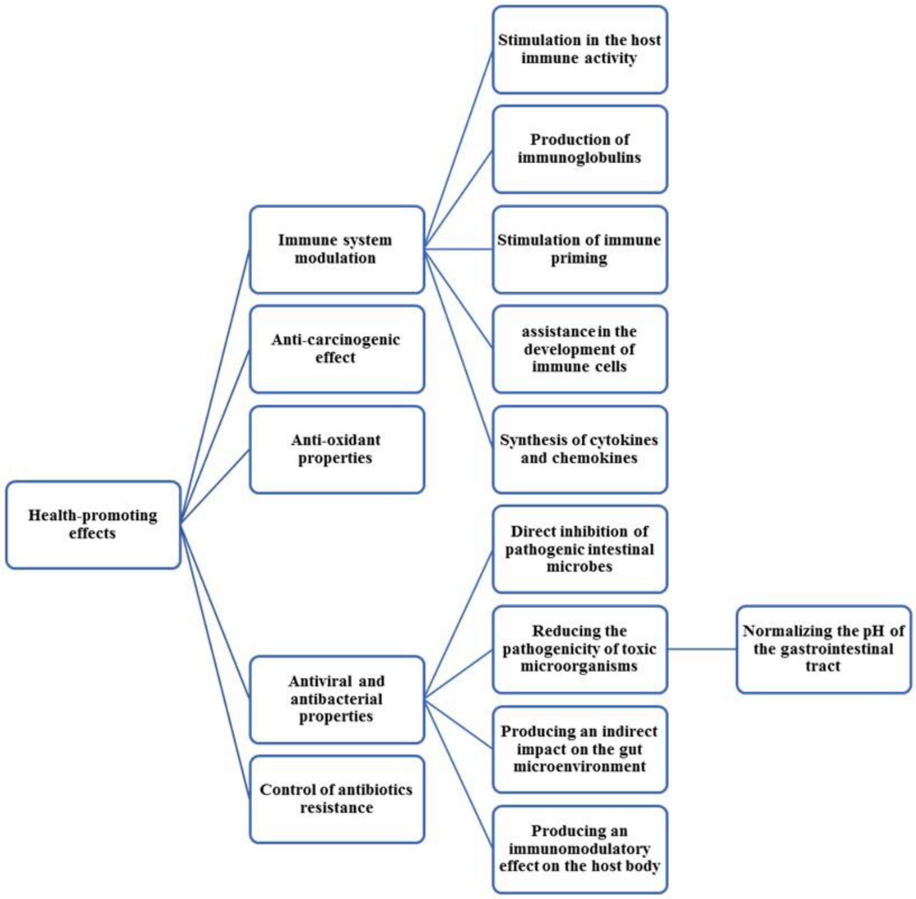

Fig. 1. Health-promoting effects of *Saccharomyces boulardii* for poultry and livestock

Adhesion capacity to intestinal cells (i), feed digestibility (ii), stimulation of digestive enzyme activity (iii), immunostimulant impact (iv), high acidity tolerance (v), bile salts resistance (vi), and improvement of gut morphological structure (vii) (17).

Health effects of *S. boulardii* for livestock. Increased IgM and IgA activity against pathogens, improved mucosal immunity, bioremoval of mycotoxins, improved gut microbiota, and a reduction in postweaning diarrhea are all potential benefits of yeast supplements in livestock feed (18). Also, the advantages of yeast as a probiotic in livestock feeds were detailed in a study (19). According to their findings, adding live yeast can enhance fiber digestibility, reduce infection growth, produce antibiotic compounds, improve gut structure, and boost the immune system.

The gut is the site of nutrient absorption as well as the animal's first line of defense against infections and other hazardous chemicals. *S. boulardii* may play a substantial function in immunomodulation in this anatomical site (20). Magalhães et al. (21) attempted to evaluate certain innate immune system parameters in vivo and discovered that feeding yeast culture products to calves was not effective. According to their results, the presence of oligosaccharides in yeast culture could have increased neutrophil phagocytic activity.

Zhang et al. (22) discovered that using *S. boulardii* mafic-1701 decreased the pro-inflammatory cytokines IL-6 and TNF-α levels in weaned piglets. In another study, *S. boulardii* was found to reduce IL-6 and TNF-α levels in rat ulcerative colitis carcinogenesis models (23).

The microorganisms in the mammalian gut are extremely diverse. The gut is thought to be home to 500-1000 bacterial species. The gut microbiota and the host have a symbiotic relationship. As Zhang et al. (22) discovered in the colon of weaned piglets, Proteobacteria were more prevalent after oral intake of feed supplements such as *S. boulardii* than Firmicutes and Bacteroidetes.

A healthy calf will grow quickly and perform well in the future (21). Calves may experience heat stress as a result of stressful environmental variables, including higher temperatures and excessive humidity. Due to decreased feed intake, compromised homeostatic processes, and changed physiological conditions, including the endocrine and immunological systems, calves exposed to heat stress perform poorly in terms of growth. As a result, decreased feed intake and decreased physiological responses may occasionally result in calf death, calf diarrhea outbreaks, and poor growth (25). When *S. boulardii* CNCM I-1079 is added to milk replacer, it can decrease the harmful effects of heat stress on Holstein dairy calves (26). In contrast, a prior study found that after giving *S. boulardii* to calves through oral infusion, neither the calves' development nor their ability to consume dry matter improved (27). These findings imply that *S. boulardii* can increase dry matter intake while having no impact on body weight gain in calves at this stage of their growth cycle.

Health effects of *S. boulardii* for poultry. Using *S. boulardii* can help prevent diarrhea in chiecken (28). According to a recent study, *S. boulardii* was effective to increase enzyme activities, improve morphology, and induce cytokine production in the duodenum (7). Also, adding *S. boulardii* to bird diets has been demonstrated to improve the sensory and qualitative attributes of meat generated from animals as well as the immune response of the birds (29).

The function of *S. boulardii* as a pathogenic bacteria reducer. Increased resistance to infection by enteric pathogens such as *Salmonella, Campylobacter jejuni, C. perfringens*, or *E. coli* is a benefit of yeast probiotic supplements in poultry (30). Because of *S. boulardii*'s antagonistic effect, it can lessen pathogens' transmission and emission, reduce permeability of diarrhea, improve clinical signs, enhance immunity, and cause overall health and disease resistance. Also, they suppress foodborne pathogens like *Salmonella, E. coli*, and *Campylobacter*, thus improving nutrient absorption and intestinal digestion, and also supporting a healthy microecological state (2). *Campylobacter* is present in farm area, and causes campylobacteriosis in broilers (31). *S. boulardii* can inhibit its growth in poultry (32).

According to Abudabos et al. (33), broilers infected with *Salmonella* who were fed diets supplemented with *Bacillus subtilis, S. boulardii*, and oregano showed improvements in plasma total protein and glucose levels. Probiotics' capacity to enhance dietary protein digestion and utilization by raising the small intestine's absorptive efficiency may be responsible for the rise in blood protein levels. It is still unknown how *S. boulardii* reduces *Salmonella* colonization. Potential mechanisms include yeast's ability to agglutinate pathogens such as *Salmonella* and *E. coli*, both of which express mannose-specific type-1 fimbriae (34).

The impact on gut microbiota and protection against *Campylobacter jejuni* infection in broilers are reported after consumption of 10^9 CFU/kg of *S. cerevisiae boulardii* CNCM I-1079 (31). It also suppressed *Salmonella* colonization in the caeca of broilers, and intestinal properties were improved in poultry fed 2.5 g yeast culture/kg of feed (35). Produced metabolites have the capacity to suppress pathogenic flora while boosting commensal bacteria (24). Recent research suggests that feeding *S. boulardii* CNCM I-1079 to calves during thermal neutral and heat stress periods increased the population of fecal yeast (26).

There are several hypothesized ways by which *S. boulardii* inhibits infections, including competition for resources, competition for colonization sites on the intestinal epithelium, generation of toxic substances, including volatile fatty acids and bacteriocins, and immune system modulation. One, more than one, or all of these processes may be present in the inhibition process in a balanced manner (36).

The function of *S. boulardii* as an antibiotic alternative. To prevent illnesses and increase productivity, antibiotics are added to livestock and poultry feed at sub-therapeutic levels. Howeever, microbial resistance, and antibiotic residues in meat and eggs are new problems in this context (37). So, use of antibiotics as growth promoters has been forbidden in the European Union since 2006 while dietary probiotics, such as *S. cerevisiae* and *S. boulardii*, have been employed as immunomodulators and antibiotic substitutes (36).

Mode of action of *S. boulardii*. Determining the mechanisms of microbial colonization within the digestive system is critical (38). *S. boulardii* possess a few different mechanisms as a therapeutic probiotic, which are summarized in Fig. 2.

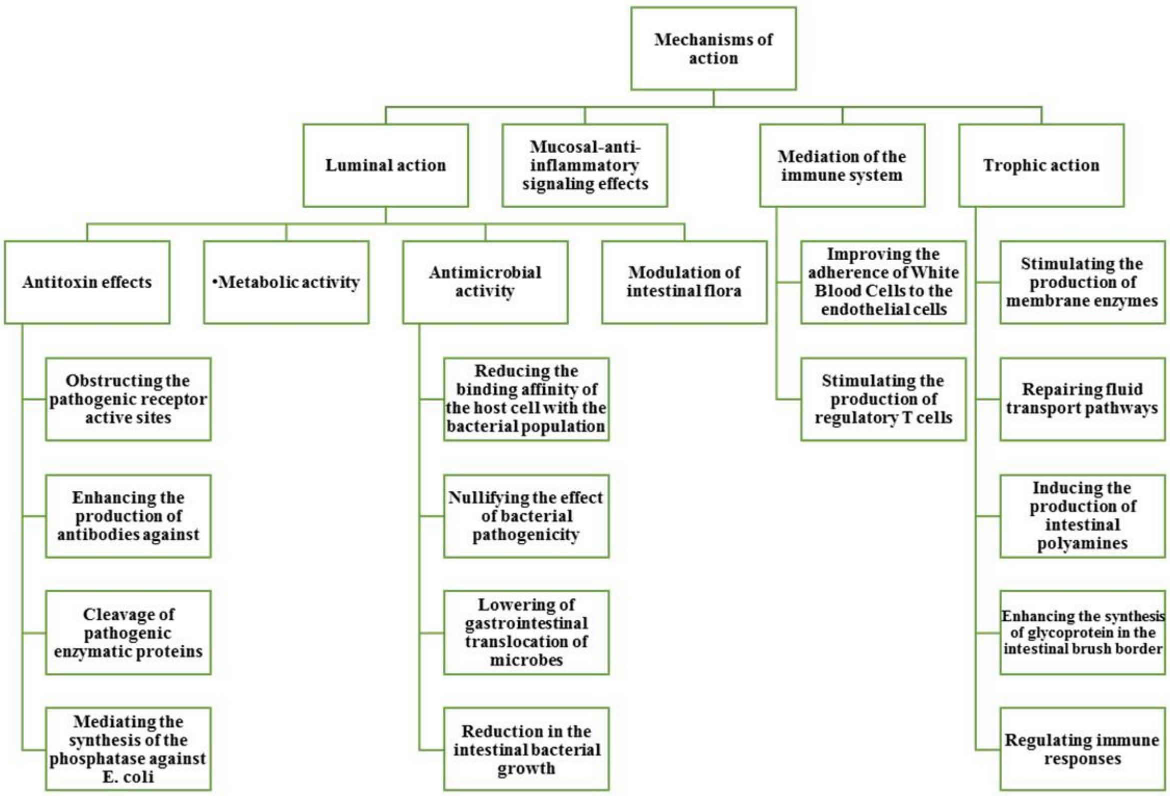

Fig. 2. Different types of *Saccharomyces boulardii*'s mechanisms of action as a therapeutic probiotic

S. boulardii exerts its beneficial effects through bio-regulatory functions, such as microbial antagonism and immune stimulation (1). Rajput et al. demonstrated that *S. boulardii* regulates intestinal morphological ultrastructure, however, the precise mechanism remains unknown. During its intestinal transit, it also secretes polyamines, primarily spermine and spermidine, which impact protein synthesis (5).

S. boulardii is one of the few yeasts that can develop quickly in anaerobic environments by consumption of oxygen in ruminal fluid (39). Nutritional rivalry and delivery of nutrients, which cause stimulation of the growth of rumen bacteria and anaerobic fungi, are other possibilities for the in vivo mode of action (40).

S. boulardii exhibited antibacterial activity for the following reasons: (i) synthesis of protease, an extracellular enzyme (ii) enzyme-based proteins secretion, (iii) SO_2 gas and toxins excretion, which can inhibit the efficacy of *Clostridium difficile* toxins, (iv) hydrophobicity of cell surface, which is responsible for the attachment of patient's intestinal lining to *S. boulardii* (41). Also, *S. boulardii* in feed has been shown in studies to decrease the gut pathogens population by inhibiting the destructive microbes' growth. This yeast facilitates digestion through enzymatic action and creates lactic acid (42). It is possible that *S. boulardii*'s beneficial effects on intestinal detoxification, modulation of intestinal mucin dynamics, immunomodulation, and stimulation of secretory IgA secretion in the gut could explain *S. boulardii*'s ability to reduce pathogens such as *Salmonella* (43).

Mannose residues and cell wall proteins of *S. boulardii* are responsible for attachment to gut receptors, lowering the likelihood of pathogenic bacteria attaching to active sites. If pathogen has already adhered, probiotic therapy may greatly increase the expression of exogenous sugars, which can hinder pathogenic microbe attachment to the gut mucosal layers (44). In poultry, it has been proposed that mannan-oligosaccharides in *S. boulardii* cell walls agglutinate to the pathogenic bacteria's Type-1 fimbriae structures, preventing their colonization of the gut lumen (34). Since the animal body cannot produce the α-glucans component of the yeast cell wall, and they are not a part of its body, pattern recognition receptors in the lumen recognize them as pathogen-associated molecular patterns. The innate immune system's natural killer cells, macrophages, and neutrophils are involved in this response (45).

Many positive impacts of yeasts are proposed to stimulate immune modulation due to β-D-glucan of the yeast cell walls (46). According to Shen et al. (47), yeast cells' ability to offer these advantages is due to the nature of the cells themselves. The effects of yeast cells are assumed to be caused by specific sugar types, particularly α-D-mannans and β-D-glucans, which make up significant portions of the cell walls of *S. boulardii*.

Various strains of *S. boulardii* have been utilized to improve nutrition, health, and production qualities in a wide range of livestock and poultry animal species, with some studies revealing quantifiable improvements and others showing no impact (48).

Effect of *S. boulardii* on production parameters. Several studies on the impact of *S. boulardii* on ruminant performance parameters have been published. There is research on the efficacy of this yeast on milk production, which revealed that *S. boulardii* increased milk yield and that yeast supplementation had no impact on milk composition (49). Additionally, the growing benefit of including *S. boulardii* in ruminant feed (such as increased heart girth, live weight, height at withers, and cut-out yields) has been reported (42). According to Shen et al. (47), adding 0.5% yeast improves nursery pig production traits, which supports the findings of Gao et al. (35), who discovered that adding yeast improves daily gain in pigs. The observed increase in litter and pig weight gains in yeast could be attributed to a variety of factors, including enhanced sow milk production and milk quality, as well as improved nutrient digestibility (49). Parada et al. (50) reported the impact of probiotic *S. boulardii* RC009 and *Pediococcus pentosaceus* RC007 on pig meat composition and increased essential omega-3 fatty acids after slaughte.

Experiments have revealed disparities in performance after feeding *S. boulardii* to calves both before and after weaning. Some studies observed much higher pre-weaning consumption, while others found no significant differences. Others reported that *S. boulardii* has a favorable effect on dry matter intake just after weaning. Dry matter intake could be influenced by a variety of factors, such as the composition of the diet or the calves' physiological status, dosage, and feeding technique (24). The average daily gain is proportional to the amount of dry matter consumed. Higher dry matter intake is likely to result in higher average daily growth. However, the average daily increase was not statistically different, corresponding to the lack of changes in dry matter intake in most studies.

Numerous studies have examined the impact of *S. boulardii* on a variety of chicken performance factors, such as immunological function, body weight gain, enhanced feed intake, and feed efficiency in broilers (36). Incorporating this probiotic in poultry processing suppressed pathogens and led health benefits (51). The findings of some researchers reported better weight gain and meat quality improvement in broilers fed yeast-based diets (52). Also, previous studies have shown that *S. boulardii* culture can improve the feed conversion ratio in laying chickens. The addition of yeast to layer feed increased egg and yolk weight, shell weight and thickness, and decreased yolk cholesterol (53).

According to a study by Magnoli et al. (54), the whole yeast and its derivatives could increase the meat yield of broilers through their impact on the numbers of white blood cells, lymphocytes, and monocytes, which may be linked to a reduction in the stress induced by *Salmonella* lipopolysaccharide in broilers. Meat-typed chickens fed a diet containing *S. boulardii* had higher protein and fiber digestibility (42). The observed enhancement in fiber and protein digestion could be attributed to the ability of yeast to enhance useful microbes in the gastrointestinal tract.

Dietary inclusion of *S. boulardii*-derived postbiotic. The metabolism of host-indigestible feed elements is an important and well-understood activity of the gut microbiota. This capability of the microbiome significantly enhances the host's energy consumption from feed. The gut microbiota has impact on host's signal transduction and often act as regulators of host response (55). Postbiotic byproducts include bacteriocins, short-chain fatty acids, proteins, and functional peptides (56). In other words, postbiotics are generally viewed as preparations made from the bioactive substances generated in regulated fermentation processes by specific microorganisms, such as yeasts, that ultimately benefit the health of the target host as a newer category of products (57).

Several metabolites associated with *S. boulardii* have been identified as potential postbiotics, including polyamines, organic acids, enzymes, vitamins, and phenolic compounds. In terms of intracellular components, biofilms, mannoproteins, ß-glucans, and chitin have been noted for their technological applications and health benefits (58). Among the various cell components, polysaccharides that constitute the cell wall structure have received the most attention from researchers. The polysaccharide composition of *S. boulardii* cell walls exhibits variability depending on the growth medium and strains. However, extant literature reports that the structure is composed of ß-glucans (65%), mannoproteins (35-40%), and chitin (2%) (59). Among the most extensively studied yeast postbiotics is beta-glucan, a polysaccharide present in the cell walls of yeast. Research has demonstrated that beta-glucans can enhance immune responses in animals by stimulating macrophages, promoting cytokine production, and improving gut barrier function (60). Moreover, mannoproteins, derived from yeast, have exhibited prebiotic properties by selectively fostering the proliferation of beneficial gut microbiota, such as Lactobacilli and Bifidobacteria.

The incorporation of yeast-derived postbiotics into animal feed has emerged as a promising strategy to enhance animal health, optimize performance, and minimize reliance on antibiotics. The utilization of yeast postbiotics has yielded favorable outcomes in the domains of poultry, swine, and ruminant production, as evidenced by the observed enhancement in growth performance, feed efficiency, intestinal morphology, and immune function (61). Furthermore, the natural origin of yeast postbiotics aligns with consumer demand for sustainable and environmentally friendly animal production practices. Most experts believe that yeast-derived products may be more effective when animals face illness or stressful conditions (24). Recent research revealed the role of postbiotics in the immune system (62). Abd El-Ghany et al. (63) showed that combination of feed and postbiotic treatment has promising results in immune status of broiler chickens (64). Also, the postbiotics of *Saccharomyces* cultures definitely demonstrated potential successful effects in terms of increasing the animal’s development rate as well as decreasing intestinal pathogen colonization (65).

In a review of the literature on supplements for food-producing animals, Broadway et al. (66) noted that the components of the *S. boulardii* cell wall interact with immune cells directly, bind bacteria to stop infections from colonizing, may have antioxidant and anticancer activities, and can improve growth performance and change metabolism. The yeast cell walls of *S. boulardii* contain mannan oligosaccharides, and they are a natural feed additive that encourage the development of useful bacteria in the gut while discouraging the growth of harmful bacteria. The effect of the yeast cell wall (0.1% and 0.2%) on broiler growth has been reported (42). Johnson et al. (62) reported that in the presence of pathogenic *C. perfringens*, water treatment with postbiotic metabolites of *S. boulardii, Lactobacillus reuteri,* and *L. acidophilus* activated immunological responses. In an in vitro model of the intestinal mucosa, a combination of heat-inactivated probiotic strains, including *S. boulardii*, *L. acidophilus, L. casei, L. plantarum, Bifidobacterium bifidum, L. rhamnosus*, and *Streptococcus thermophilus* protected the midgut from becoming infected with *E. coli* by lowering pathogenic penetration and paracellular permeability into the intestinal epithelium and returning tight linkage activity (67).

Table 1 shows some of the recent studies, in which the impact of supplementation of poultry and livestock diets with *S. boulardii* was investigated (68-75). Anyway, besides all the benefits of *S. boulardii* and its metabolites as a single or coculture system (76-79), *S. boulardii* has the potential to open new windows for human health by improving feed and food safety.

The Antimicrobial resistance crisis in animal production. The extensive use of antibiotics in livestock has created a significant public health challenge through the development of antimicrobial resistance. Since their introduction in the 1940s, antibiotics have been used not only for disease treatment but also as growth promoters in animal feed. The European Union's ban on antibiotic growth promoters in 2006 (Regulation EC No 1831/2003) and the growing consumer demand for antibiotic-free products have accelerated the search for effective alternatives, with probiotics emerging as a leading solution.

Research demonstrates numerous benefits of probiotic supplementation in poultry by improving growth performance, pathogen reduction (*Lactobacillus* strains reduce *Salmonella* contamination in chickens, *Pediococcus pentosaceus* produces pediocin that inhibits *Clostridium perfringens, Bacillus subtilis* limits *Campylobacter* colonization), as well as gut health and even meat and egg quality. In cattle and other ruminants, probiotics reduce shedding of *E. coli* O157:H7, improve feed efficiency and nutrient digestibility, and enhance immune responses against respiratory pathogens like *Mannheimia haemolytica*.

Table 1. Impact of supplementation of poultry and livestock diets with live *Saccharomyces boulardii*

***Saccharomyces boulardii* doses**	**Animal species**	**Condition**	**Impact**	**References**
1.0×10^9 CFU/kg feed	Pigs	1650 pigs	Increasing lean percentage and reducing the eicosanoic contents in meat	(50)
1.0×10^{12} CFU/T feed	Broiler chicken	Two hundred and four 1-day-old male broiler chickens	Enhancing productivity parameters, economically significant carcass weight, and histomorphometric characteristics in the small intestine	(54)
1.0×10^8 CFU per head	Dairy cows	33 Primiparous and 35 multiparous cows	Production of greater milk yield as well as more energy-corrected milk with better feed efficiency	(68)
3 g/day/calf for 21 days	Dairy calves	48 newborn Holstein dairy calves	Reducing the incidence of diarrhea, improving serum immunoglobulins concentrations and modulating rectal microbiota	(69)
1.0×10^8 CFU/kg of feed for 28 d	Weaned piglets	One hundred and eight weaned piglets	Improvement in feed conversion ratio, reduction in diarrhea rate, enhanced antioxidant activity, anti-inflammatory responses, improved intestinal microbial ecology	(22)
1.0×10^8 CFU/kg of feed for 42 d	Broiler chickens	750 one-day-old male broiler chickens (Ross 308)	Improvement in growth rate and bone mineralization, not effective for feed efficiency	(70)
1.0×10^9 CFU/d for 49 days	Veal calves	84 animals	Reducing diarrhea and improvement of fecal scores	(71)
2.0×10^{10} CFU/g for 21 d	Holstein calves	28 days of age, body weight of 45.6 kg	Amelioration of the negative impact of heat stress; reduction in rectal temperature and heart rate; alleviation of diarrhea	(26)
1.0×10^9 CFU/kg of feed for 21 d	Broilers	156-day-old male Ross 308 chicks	Modulation of the intestinal ecosystem, higher abundance of beneficial microorganisms and modification of the intestinal mucosa architecture, improvement of the broilers' growth performance	(31)
1.0×10^8 CFU/g of feed	Broiler chicken	600 chicks (Ross 308)	Significantly high concentration of blood protein and glucose, significantly low aspirate aminotransferase	(33)
1.0×10^8 CFU/kg of feed for 72 d	Broilers	Three hundred 1-day-old Sanhuang broilers	Bacteroidetes, Proteobacteria, and Verrucomicrobia observed at a much higher abundance in the jejunum and ileum	(72)
Microguard at 50 g/ton for 42 days	Broilers	Six hundred one-day-old male Ross 308 broilers	Enhancing immune system responses and inducing beneficial modulations in the caecal microflora	(73)
1.0×10^8 CFU/kg of feed for 72 d	Broiler chickens	200 one-day-old Sanhuang broilers	Higher adenosine triphosphatase, gamma-glutamyl transpeptidase, lipase, and trypsin activities; no significant improvement in amylase activities in the duodenum	(7)
1.0×10^9 CFU/kg of feed for 35 d	Broilers	430 one-day-old male Cobb broilers vaccinated for Marek, Infectious Bronchitis, and Newcastle Disease	Improvement in growth performance; reduction of *Salmonella* presence	(43)
0.05 lb. per ton of feed	Broiler chickens	From day eighteen to day thirty-six of the flock	No significant impact on production characteristics	(28)
1.0×10^8 CFU/kg of feed for 72 d	Broiler chickens	Three hundred 1-day-old Sanhuang broilers	Significant improvement in live BW, increase intestinal villus height, width, and number of goblet cells	(5)
2.6×10^8 CFU/g for 35 d	Weaned pigs	96 weaned piglets (21-24 days of age, 7.4 ± 0.6 kg body weight)	Improved average daily gain and feed conversion ratio, higher apparent total tract digestibility of crude protein, crude fiber, and organic matter	(74)
1 g/d from 4 d of age until weaning	Calves	24 Holstein calves (12 males, 12 females)	Modified ruminal fermentation, no impact on productive performance	(27)
1.0×10^7 CFU/g of feed for 47 d	Broiler chicken	Ninety 1-d-old female chicks (Ross-308)	Improvement of feed efficiency	(75)

Probiotic use in fish farming shows reduced mortality from bacterial infections (e.g., *Edwardsiella tarda* in tilapia), improved immune defenses in species like rainbow trout, better growth performance and survival rates (9, 11, 12, 21, 47, 71).

Probiotics as a solution to antimicrobial resistance. The transition from antibiotics to probiotics addresses AMR through several key mechanisms of reduced antibiotic use (by preventing infections and improving growth, probiotics decrease reliance on therapeutic antibiotics), pathogen control without resistance by multiple antimicrobial strategies (competitive exclusion, pH reduction, bacteriocins), restoration of microbial balance, and reducing environmental AMR pressure. While promising, probiotic use in animal nutrition faces several challenges, including strain-specific effects (e.g. *Lactobacillus acidophilus* improves egg production while *L. plantarum* is more effective against *Salmonella*), dosage optimization for each animal species and production system, stability issues, regulatory frameworks, and their synergy with essential oils.

Current research on probiotics in livestock primarily investigated short-term effects; however, long-term studies are crucial to evaluate sustained benefits. Key areas of focus include understanding the molecular mechanisms of probiotic interactions with animal physiology, exploring synergistic effects between probiotics, prebiotics (synbiotics), and other natural additives. Further research should concentrate on utilizing advanced molecular techniques to identify optimal probiotic strains, elucidate their modes of action, and develop customized probiotic formulations tailored to specific livestock breeds and production systems (80).

CONCLUSION

The application of probiotics in livestock and poultry feed represents a paradigm shift in sustainable animal production. By enhancing animal health through multiple mechanisms from competitive exclusion to immune modulation, probiotics offer a viable solution to reduce dependence on antibiotics while maintaining productivity. Their ability to control pathogens without promoting antimicrobial resistance addresses one of the most pressing challenges in modern agriculture. As research continues to refine probiotic formulations and application methods, their role in animal nutrition is poised to expand. The integration of probiotics into animal feeding strategies not only benefits animal health and welfare, but also contributes to broader public health goals by mitigating the global AMR crisis. With proper strain selection, dosage, and management, probiotics can help meet the growing demand for safe, sustainable animal protein in the 21st century.

It has the potential to improve animal health and performance, enhance digestibility, and reduce pathogenic microbes. *S. boulardii* shows promise as a probiotic for poultry. Research indicates it can improve gut integrity, prevent bacterial translocation, and stimulate the immune system in chicks. Moreover, both live and heat-killed forms of *S. boulardii* have demonstrated effectiveness. This offers a safe alternative to in-feed medications. S. boulardii plays its role in domestic animals through one of these mechanisms or their combinations: (i) decreasing the pathogens through competing for available sites, (ii) lowering the pH of the gastrointestinal tract via producing a wide range of organic acids, (iii) improving nutrient uptake and feed intake via direct nutritional influence, and (iv) decreasing bacterial enzymatic activity. More investigations could focus on clarifying the exact mechanism of action of *S. boulardii* in the domestic animal gut.

However, the inconsistency in most of the results as reported by researchers could be related to these factors: *S. boulardii* dosage, the count of live cells, the impact of age and physiological status of the host animal, geographical differences, environmental factors, the composition of the diet, the mode of administration, and production techniques. Also, the variability in experimental designs may contribute to the differences in reported results. Further research is needed to elucidate the exact factors affecting the differences in experimental results. Also, more research is required to optimize dosage, explore its combinations with other probiotics, and expand research to various livestock species to determine its full potential and application. Unsolved problems are still its optimal dosages for poultry, its comparison to other probiotics, and safety concerns.

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