KAVAKA 60 Special Issue: 93-106 (November 2024) DOI: 10.36460/Kavaka/60/sp/2024/93-106

Perspectives of Yeast, Molds and Mushrooms as Pro and Prebiotics for the Improvement of Gut Health and Microbiome: A Review

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(Submitted on June 21, 2024; Accepted on 25 September, 2024)

ABSTRACT

Probiotics are diverse live microorganisms (including bacteria, yeasts and molds) that confer good number of health promoting activities to the host when ingested in adequate amount. Functional foods are fortified with these probiotics and have improved human health in addition to the therapeutic applications. In addition to Lactobacilli and Bifdobacteria, good number of yeast, molds and mushrooms act as pre and probiotics and thus help in health promotion. The ability to survive in the gastrointestinal tract, salt tolerance and adherence to intestinal epithelial cells, co/auto aggregation are the few prerequisites to be probiotics. In this review, we emphasise and promote the use of fungal strains (yeasts, mold and mushroom) as pre and probiotics for immunomodulatory effects and for functional properties. Thus, fungal species would be promising candidate as pre/probiotic strains.

Key words: *Saccharomyces, Aspergillus oryzae*, Inulin, Fructans, Probiotics, Prebiotics, Synbiotics, Mushrooms

INTRODUCTION

The word probiotic was derived from the Greek, which is meant "for life" and was first authored in 1965 by Lilley and Stillwell (Banik *et al.,* 2019). In 2002, FAO/WHO defined probiotics as the "live microorganisms, which when administered in adequate amounts, confer a health benefits on the host". During the present days, the practice of manufacturing nutritional compounds as therapy using microbes is growing globally as multibillion-dollar industry and probiotics are commonly used as food supplements worldwide due its beneficial effects. The US Food and Drug Administration (FDA) designated probiotics with Generally Recognized as Safe (GRAS) status when added to food (http://www.fda.gov/food/IngredientspackagingLabeling/GRAS/) (Doron and Snydmon, 2015).

The probiotic microorganisms are mainly originated from fermented food and milk products and due their positive effects on human health they have been consumed from centuries as traditional food (Zucko *et al.*, 2020). Probiotic microorganisms have ability to alter the gut dysbiosis and maintains the gastrointestinal health (Zucko *et al.*, 2020). Currently, the probiotic spp. that are most commonly used include species of *Lactobacillus* and *Bifidobacterium* and probiotic bacteria of the other genera are *Streptococcus*, *Enterococcus*, *Pediococcus*, *Propionibacterium*, *Bacillus* as well as *Escherichia coli* (Szajewska *et al.*, 2016).

Probiotics may in anticipation of the overgrowth of pathogenic bacteria, improves the resistance of the gut to avoid the invasion of pathogens, elevates barrier function of epithelial tissue lining the gastrointestinal (GI) tract, and also ameliorate disease processes by inducing the secretion of essential secondary metabolites, soluble factors such as SCFAs and antimicrobial compounds (Cremon *et al.*, 2018). The use of probiotics has also been recommended in treating other health disorders such as lactose intolerance, food allergy, Crohn's disease, acute infectious diarrhoea in infants and children and also deadly diseases such as rheumatoid arthritis and colon cancer by increasing immunity in the body. Further, the probiotic *Lactobacillus* spp. are used in the treatment of type II diabetes, obesity and also utilized as starter culture in the production of yoghurt and ice cream (Evivie *et al.*, 2017). In this review, the perspectives of yeast, molds and mushrooms as pro and prebiotics for the improvement of gut health and microbiome are discussed.

THE MECHANISM OF ACTION OF PROBIOTICS

The mechanism of action of probiotics are as follows: colonization of probiotic microorganisms over the receptors binding to the intestinal lining to prevent the adhesion of pathogenic bacteria, co-aggregation of probiotics and pathogenic bacteria prevents the growth of the pathogenic organisms by increasing population of probiotics, probiotic bacteria consume the available nutrients and creates the competition for nutrients to undesired bacteria for their growth and survival, increased synthesis of lactic acid by probiotic microbes reduce the intestinal pH to acidic make the environment unfavourable for pathogens, boost the production of specific antibacterial substances, reduce the production of toxic amines and decrease the level of ammonia in the GI tract, make wholesome effects on the intestinal immune system with improved defence against bacterial and viral infections and enhance antioxidant properties by reducing scavenging activity of oxygen free radicals (Julio *et al.*, 2019).

With the advent of advantageous effects of probiotic microorganisms over the humans, the term prebiotics also shredded its wings. Gibson *et al.* (2004) were the pioneer to propose the term prebiotic as the dietary substances which have the ability to alters host microbiota that inducing benefit to the host. During their time, the foremost studied prebiotic examples were fructans and galactans, these two together enriches the growth and multiplication of native *Lactobacillus* spp. and/or *Bifidobacterium* spp. Along with fructans and galactans, the oligofructose, galactooligosaccharides, lactulose, and breast milk oligosaccharides are also well characterized as prebiotics. The International Scientific Association for Probiotics and Prebiotics defined prebiotic as 'a substrate that is selectively utilized by host microorganisms conferring a health benefit' (Cremon *et al.,* 2018).

Other than bacterial species many microorganisms do harbours humans, for example abundance of fungal and archaeal species are well documented (Hoffmann *et al.,* 2014). There are various fungal species that play a unique role in GI homeostasis in humans and also in other mammals. According to Human Mycobiome Project, the genera of fungi that reside in the human gut are species of *Saccharomyces, Malassezia* and *Candida* in descending order of abundance (Nash *et al.,* 2017).

Fungal species exhibit some symbiotic benefits to the human host such as boosting adaptive immunity, maintenance of microbial homeostasis in the gut through specific interactions by eliminating pathogen and modulating immunological homeostasis (Lai *et al.*, 2019).

Apart from bacteria, several diversified groups of the beneficial fungal species are opening new arena in the probiotic market and have captivated the attention of industries and many researchers concerning about their commercial perspectives. Fungi are basically non-photosynthetic, spore-bearing heterotrophic eukaryotic organisms that reproduce both sexually and asexually by spore formation and budding, respectively. Fungi majorly include microscopic molds, yeasts and macroscopic mushrooms. Molds are the important group of fungal species that grow in multicellular filaments called hyphae. Both unicellular microscopic yeasts and molds have the great importance in food processing and fermentation technology (Banik *et al.*, 2019). A group of fungal species particularly species under yeast genera have been reported as novel candidates in the probiotic family which include: *Candida humilis*, *Debaryomyce shansenii*, *Debaryomyces occidentalis*, *Kluyveromyces lactis*, *Kluyveromyces lodderae*, *Kluyveromyces marxiamus*, *Saccharomyces cerevisiae var. boulardii*, *Pichia kluyveri*, *Issatchenkia orientalis*, *Pichia kudriavzevii*, *Candida tropicalis*, *Meyerozyma caribbica*, *Candida saitoana*, *Candida pintolopesii*, *Cryptococcus albidus*, and *Torulaspora delbrueckii* (Banik *et al.*, 2019).

Like bacteria, several fungal species also reside in the gastrointestinal tract and might provide a symbiotic benefit to the human host, alter the immunological homeostasis by increase adaptive immunity (Sen and Mansel, 2020). Fungi such as yeast bear unique cellular architecture, their cell envelope composed of two layers, outer layer is composed of mannan (phosphopetidomannan or phospholipomannan) whereas inner layer contains chitin and 1,3- and 1,6-β-glucan which allows easy absorption in the GI tract. Some fungi also grow optimally in varied temperatures. This characteristic feature makes fungi the acceptable class of probiotics along with commercially available bacterial probiotics. Major criteria for the organism to be considered as probiotic is its antagonistic property. Some fungal species are antagonistic toward numerous microorganisms that inhibit the growth of pathogenic bacteria in the gut and therefore, the fungal species have fulfilled the potentialities of a good-probiotic candidate (Banik *et al.*, 2019).

A synbiotic product is a food ingredient or dietary supplement that combines pro- and prebiotics in a way that promotes human and animal health through synergism, hence the name synbiotics. The FAO advises against using the word "symbiotic" unless there is a net health advantage, i.e., when the effectiveness of one probiotic or prebiotic truly outweighs that of the other (Pandey *et al.*, 2015). Bacteria such as *Lactobacillus* or *Bifidobacterium* combined with fructooligosaccharides (FOS) is the most often used synbiotic. To be used selectively by probiotics in the caecum, a prebiotic molecule needs to be able to transit through the small intestine without undergoing breakage or absorbed by bacteria or the host. Prolonged ingestion of a symbiotic mixture containing the probiotic *Lactobacillus fermentum* and the prebiotic β-glucan from *Sparassis crispa*, a type of cauliflower fungus, hindered menopausal symptoms and enhanced the microbiota of the gut (Jeong *et al.*, 2017). It is crucial to understand that probiotics come in a huge diversity with effects particular to individual strains and it is difficult to delineate the benefits and drawbacks across various products in the market (Falandysz, 2008). The probiotics and prebiotics properties of fungi are illustrated in the **Figure 1.**

Figure 1: Prebiotic and probiotic properties exhibited by fungi (Yeasts, Molds and Mushrooms).

MOLDS AND THEIR PROBIOTIC PROPERTIES

Molds are multicellular organisms classified under the kingdom 'Fungi'. They consist of common molds reported throughout the environment within soil, water or vegetation and thrives as saprophytes. Among many filamentous fungi, *Aspergillus* spp. have been recognized as an essential source of diverse enzymes, e.g., alpha-amylase, protease and glucoamylase and recommended for use as promising probiotic feed supplements for fish, as well as poultry and livestock. *Aspergillus oryzae* as a feed supplement to the *Niletilapia* fish spp. for about 60 days potentially improved immune status and disease resistance along with growth performance and intestinal histomorphometry. The fish showed a significant increase in its growth performance and modulation of blood hematocrit, hemoglobin, red blood cells, white blood cells, total protein, digestive enzymes, villi length and the activity of antioxidative enzymes. Supplementation also enhanced nitro blue tetrazolium (NBT), IgM, lysozyme, bactericidal and phagocytosis, indicating the improved immunity of tilapia (Dawood *et al.*, 2020). In addition, the combined application of *A. oryzae* and β-glucan as symbiotic significantly improved the growth, feed efficiency, haematological parameters, digestive enzymes, immunity (NBT, IgM, lysozyme, bactericidal and phagocytosis) and antioxidative capacity of Nile tilapia. Fermented *A. oryzae* could enhanced the growth and haematological parameters of common carp (Ghosh *et al.*, 2023).

Since from the many centuries fungi have been used in the food processes, especially yeasts and molds used in the processing and manufacturing of wine, bread, cheese and many other fermented foods consumed across the world (Chen *et al.*, 2022). Comparatively yeasts are the most studied beneficial fungi than molds and data on potential probiotic characteristics of molds are scarce. However, the results to date published on potential probiotic effects of filamentous fungi (molds) are related to broiler chicks, poultry, and fish production (Melo-Bolívar *et al.*, 2020) are significant. Incorporation of molds in the diet of poultry and fish has various advantages including growth promotion, inhibition of pathogen colonization, improvement of nutrient digestion and enhancement of reproductive property (Sugiharto, 2019). Two interesting fungal isolates *Acremonium charticola* and *Rhizopus oryzae* isolated from Indonesian fermented dried cassava possessed antibacterial, antifungal, and antioxidant activities, gastrointestinal resilience of the chickens, which were added boon for the betterment of poultry industry. Further, it has been reported that, a filamentous fungus *Monascus purpureus M1* obtained from Chinese general MCC (Microbial Culture Collection) produced Monacolin K in the presence of glutamic acid (which is a secondary metabolite) has the ability to lower the cholesterol level in the humans (Zhang *et al.*, 2020).

Like bacteria, fungi do colonise the lower part of the gastrointestinal tract of humans but comparatively in the minor population with an average of 106 fungal cells than bacteria (1011 cells) per gram of colon content. The two dominant phyla of fungi commonly present in the gastrointestinal tract are the Ascomycota and the Basidiomycota (representing 70% and 30%, respectively), some studies also identified with some Zygomycetes. However, ten genera found in the majority of human gastrointestinal tracts can be considered as a possible core gut mycobiota: *Candida* (particularly *Candida albicans*), *Saccharomyces* (particularly *Saccharomyces cerevisiae*), *Penicillium*, *Aspergillus*, *Cryptococcus*, *Malassezia* (*Malassezia restricta*), *Cladosporium*, *Galactomyces*, *Debaryomyces* and *Trichosporon*. Additionally, about 349 fungal strains isolated from faecal samples of the healthy individuals, majority of the isolates had the ability to grow at 37°C, pH 3, resist oxidative stress and bile acids, indicating that these fungal species could mimic the conditions that encountered in the gastrointestinal tract (Richard and Sokol, 2019). Guan *et al.* (2017) reported on usage of *Actinomuco relegans* as starter culture for the production of okara (a soyabean fermented drink) during submerged state fermentation (SSF) and the proteins synthesized from fungi denatured to peptides and mixed with soyabean. The SSF okara showed high antioxidant activities such as reducing power, ferrous ion-chelating activity, scavenging effect of DPPH, ABTS, and hydroxyl radicals and thus proved as a potential functional food.

Penicillium camemberti, *Penicillium nalgiovense*, *Penicillium roqueforti*, *Fusarium domesticum* and *Geotrichum candidum* were the five molds chosen for their widespread use in food industries in the production processes of some main food products, particularly cheese ripening but also in meat ripening and meat protective micro-flora development. These spore forming molds were characterised and measured for their diverse interactions with the gut and immune cells through *in vivo* experiments. Among these five the fungal strains, *Geotrichum candidum* exhibited highest anti-inflammatory effect on HT29 epithelial cells with clear reduction of IL-8 production thus possessed probiotic characteristic to reduce inflammation. This positive result initiate tests of administration of some filamentous fungi in the food, monitoring the effect on global health modification (Poirier *et al.*, 2022).

The antithrombotic bioactivity of filamentous fungi is referred to their ability to secret fibrinolytic protease. This enzyme specifically degrades fibrin, which is the main component of thrombus (Sharma *et al.*, 2021). This bioactivity has a significant role on preventing and managing cardiovascular disease by removing blood clots. Many studies have been shown the antithrombotic activities of different types of filamentous fungi such as *Neurospora sitophila, N. crassa* (He *et al.,* 2022), *Mucor subtilissimus* (Nascimento *et al.,* 2017), *A. oryzae* (Shirasaka *et al.,* 2012), *Rhizopus sp*. (Polanowska *et al.,* 2020), *R. chinensis* (Xiao-Lan *et al.,* 2005) and *Fusarium* sp. (Wu and Xu, 2011).

MOLDS AS A SOURCE OF PREBIOTICS

Prebiotics include fructans, inulin and fructooligosaccharides, galactooligosaccharides, isomaltooligosaccharides, maltooligosaccharides, xylo- oligosaccharides, soybean oligosaccharides, lactosucrose, and lactulose, however, only few are recognized as potential prebiotics (Berlorkar, 2020). It has been observed that filamentous molds are the chief source of prebiotics, while some important fungi involved in the production are *Aspergillus oryzae* and *Aureobasidium* which synthesize fructo-oligosaccharides, *Aspergillus oryzae* produces galactooligosaccharides, *Aspergillus foetidus* and *Aspergillus brasiliensis* produce xylooligosaccharides, *Penicillium purpurogenum* produces arabino-oligosaccharides, *Trichoderma harzianum* produces gluco-oligosaccharides and malto-oligosaccharides which were extracted from the cell wall of *Paecilomyces* spp. (Berlokar,2020).

β-glucan: The non-starch polysaccharide β-glucans, a component of cell wall in filamentous fungi and it is also found in the cell wall of some bacteria and cereal grains such as rye, barley and oat. The β-glucan (Oligosaccharide) is a prebiotic which is made up of β-1,3 chains with a variable degree of β-1,6 branching, helps to strengthen fungal cell structure and serves as a food reserve. Due to its high molecular weight and high viscosity properties, β-glucan showed better hypocholesterolemic and hypoglycemic index but the low molecular weight of β-glucan showed better immunostimulatory and anti-allergic activity. A detailed review of Andrade *et al.* (2015) concluded that intake of β-glucan is effective in decreasing glucose levels in diabetic patients, with higher or smaller doses for longer periods presenting better results.

Fructooligosaccharides:

The fructooligosaccharides (FOSs) are another example of prebiotics that are found in wide variety of fungi namely *Aureobasidium pullulans, Fusarium sp., Aspergillus niger, Aspergillus japonicus, Scopulariopsis brevicaulis* and *Rhizopus stolonifera*. FOSs have various effects on human health due to its prebiotic properties such as production of short chain fatty acids (SCFAs) produced through the fermentation of FOSs, can suppress inflammation and cancer, promote local immune response, and increase ammonia excretion (Liu *et al.*, 2021). Further studies revealed the therapeutic property of FOSs, which are active against prostrate, breast, ovarian and colorectal cancer. Yu *et al.* (2014) reported that the anti-tumor and immunostimulatory functions of FOSs produced by fermentation of wheat bran through *Aureobasidium pullulans*. In addition, FOSs have been shown to lower serum lipid levels, have a hypotriglyceridemic and hypocholestrolemic effect, thereby reducing the risk of diabetes, obesity and atherosclerosis (Rousta *et al.*, 2023).

YEASTS AS PROBIOTIC

Yeasts that harbor the gastrointestinal tract are *Candida albicans, Torulopsis glabratra* and *Candida tropicalis.* Yeasts account less number (<0.1%) in microbiota but found to be 10 times bigger than that of bacteria in cell size and they can also represent a significant barrier for bacteria. The word "yeast" was derived originally from the Dutch word "gist"refers to the foam formed during the fermentation of beer wort. Several yeasts are found in colon and stomach, as some yeasts can grow in the pH range of 3 and can tolerate the acidic medium up to 1.5. Therefore, yeasts are considered as good candidates of probiotics as they have probiotic characteristic resistant to local stresses such as the presence of GI enzymes, bile salts, organic acids and considerable variations of pH and temperature.

Probiotic yeasts are also utilized as biotherapeutics as they have been promising antimicrobial, antioxidant, anticancer properties, cholesterol assimilation, in addition to immunomodulatory effects. At present, commonly used human yeast probiotic which is accessible in market is *Saccharomyces cerevisiae var. boulardii.* Not only yeasts promote health but also they intensify the bioavailability of minerals through detoxification of fungal toxins, folate biofortification, and phytate hydrolysis (Didari *et al.*, 2014).

As yeasts are not affected by the antibacterial agents and also create a symbiotic stability in the host alimentary tract, thus yeasts prove to be good probiotic candidate (Shruthi *et al.*, 2022). The probiotic yeasts such as *Saccharomyces boulardii* and *Kluyveromyces marxianus* produce biomolecules and metabolites such as organic acids, polyamines, proteases, mycocins and some antimicrobial compounds. These yeasts gain additional nutrition from the prebiotics for example beta-glucan which binds to the receptors present on the epithelial cells of gastrointestinal tract, thus helps in the colonization of yeasts. Yeasts increases their number and fight against the invading pathogens and perform high antagonistic activity. The mode of antibacterial activity exhibited by probiotic yeasts was illustrated in **Figure 2.**

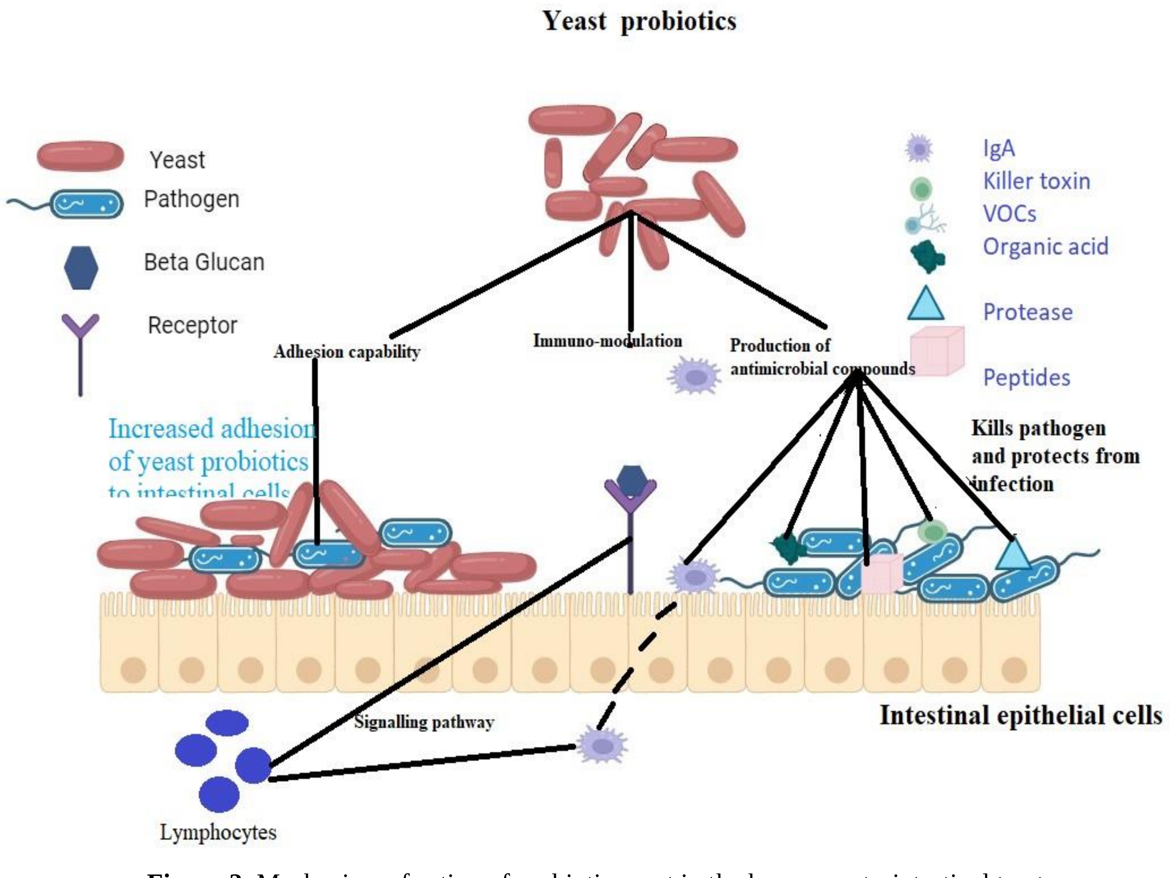

Figure 2: Mechanism of action of probiotic yeast in the human gastrointestinal tract.

Novel strains of probiotic yeasts: Other than *Saccharomyces,* some other species of yeasts have the capacity to survive in the digestive conditions and have resistance to antibiotic which has made them as a competent candidate for novel probiotics (Afalobi *et al.*, 2018) with good manufacturing properties and fulfill safety requirements.The new probiotic strains with innovative biochemical propertieshave been isolated, for instance lactase that extracellularly secreted have capability to digest whey, used as food additive in animal feed. As gastric juice in the stomach has low pH and possess inhibitory action against pathogens and also some microorganisms. But *Saccharomyces* *cerevesiae*, *Hanseniaspora osmopholia*, *Saccharomyces cerevesiae*, *Hanseniaspora osmopholia* and *Kluyveromyces thermotolerans* are unaffected by gastro intestinal tract conditions (Fernández-Pacheco *et al.*, 2019). Recent studies have shown that in addition to *Saccharomyces cerevisiae* var. *boulardii,* other species such as *Kluyveromyces marxianus* and *Pichia kudriavzevi* are also used as probiotic strains (Arévalo-Villena *et al.,* 2018). EFSA (European Food Safety Authority) has granted qualified presumption of safety (QPS) to only some yeasts such as *K. marxianus* var. *lactis* and *K. marxianus* var. *fragilis* that might be used as food additive (Stenizweski and Kordowska-waiter, 2021).

YEASTS DERIVED PREBIOTICS

Prebiotics are non-digestible polysaccharides and oligosaccharides (NDO), which help in promoting the growth of beneficial microorganisms. Yeast cell wall (YCW), yeast cultures or extracts after yeast fermentation, active yeast and purified cell wall components are the types of yeast supplements. The by-products of yeasts can also be applied in livestock production systems. Since the yeast compounds are unique in appearance, the composition of biologically active components and their application to the production system (Pang *et al.,* 2022), these prebiotics support the growth of probiotic microorganisms. In this regard, the components such as proteins and carbohydrates residues of yeast cell wall and their chemical constituents such as mannose, glucose and N-acetylglucosamine (chitin) play a crucial role. The three essential criteria that followed by prebiotic yeasts are: they particularly stimulate the growth and activity of intestinal bacteria associated with health, gastrointestinal absorption and resistant to gastric acidity (Theodoro *et al.,* 2019).

β-glucan, a prebiotic compound which is composed of D-glucose as monomer linked by glycosidic bonds also plays crucial role in immunomodulatory activity and many studies revealed that the usage of β-glucan has been found to be safe for the treatment of various diseases including respiratory, cancer and various infections (De Oliva-Neto *et al.*, 2016). Best known yeast PGG-glucans (betafectin) that are isolated from *Saccharomyces cerevisiae* is β-glucan as it enhances the immune response by stimulating the growth and also increased the function of WBC. And it involves in the stimulation of neutrophiles/heterophiles, monocytes, macrophages, and dendritic cells (Bilal *et al.,* 2023).

Mannooligosaccharides are another important prebiotic compounds that were extracted from yeast which act as immune stimulant. They also stimulate the production of cytokines and known to alter the gene expression of the TLR (toll-like receptor) (Teng and Kim, 2018). Mannooligosaccharides maintain their structures and also function intact under high pressure feed processing and pelleting conditions which also have the application in poultry breeding and feed additive in livestock (Chen *et al.,* 2005).

Inulin is another yeast prebiotic compound that helps in production of IgA antibody, particularly that fight against antigens in mucous membrane (Huang *et al.,* 2015). The components of yeast cell wall which act as prebiotics promote the SCFA (short chain fatty acids), regulation of colon pH and competition against pathogens for cell mucosa receptors. And some studies report that the primary target of the immunomodulatory effect of prebiotics is GALT (gut associated lymphoid tissue) (Theodoro *et al.,* 2019). While, this prebiotic is used in synbiotics mixture to have synergistic impact which may include an increased growth of beneficial microorganisms, balancing gut microbiota, disease resistance and stimulating immunological response (Del Valle *et al.,* 2023).

MACROSCOPIC FUNGI - MUSHROOMS AND THEIR PROBIOTIC AND PREBIOTIC FEATURES

Mushroom cultivation has a long tradition in Eastern Asian countries, especially in China, where it started around 600 A.D. with *Auricularia auricula* (Wood Ear). In Europe, cultivation of *Agaricus bisporus*, the button mushroom was first achieved in France during the seventeenth century (Kues and Liu, 2000). As per Chang (1999) observation, there are 12,000 species of mushrooms, of which at least two thousand species are edible. While, Sanchez (2004) reported, more than two hundred species, primarily from the Far East, have reportedly been collected from the wild forest and employed for various traditional medicinal purposes. In one of the studies on mushrooms, twenty out of 35 species are grown industrially. *Auricula auricula*, *Lentinus edodes, Pleurotus* sp., *Volvariella volvacea* and *Agaricus bisporus* are the most widely grown mushrooms in the world (Fokunang *et al.,* 2022). In China, Japan, and Korea, mushrooms have been used for several years as food and medicinal product. In some countries, dietary supplements have recently drawn significant interest as a way to improve health and well-being. The impact that mushroom products have on the gut microbiota and the inflammatory process due to the contents of β-glucans, enzymes, and secondary metabolites justify their nutritional significance as either direct prebiotics, indirect probiotics, or both (synbiotics) (Fokunang *et al.*, 2022). A number of bioactive chemicals derived from fungi are either absent or insufficient in food items derived from plants and animals for human consumption. These compounds are utilized as preventative measures against a diverse array of human ailments. Nowadays, it is known that mushrooms include nutraceuticals that can balance nutrients, boost immunity, increase natural body resilience, and reduce susceptibility to disease (Ashraf *et al.*, 2020).

Health benefits of mushrooms: In addition to being utilized as food, mushrooms also been used medicinally (Wasser, 2002). Extensive global study has established the therapeutic potential of mushrooms. According to Chang (2001), Chinese have been consuming medicinal mushrooms for more than 2000 years as a meal or dietary supplement. Products containing extractable mushroom components made claims to enhance human body function biologically and medical qualities. Eating edible mushrooms improve the health significantly as they possess a high proportion of protein, carbohydrates, fibre, vitamins, and minerals, yet are low in calories, sodium, fat, and cholesterol, thus creating a well-balanced diet (Aida *et al.*, 2009).

Nutritional components of mushrooms: Nutritional components majorly have carbohydrate (50–65% of the fruiting bodies), these sugars are called oligosaccharides, which are derived from monosaccharides. There is some alcoholic sugar present in the carbohydrate such as mannitol and trehalose. By maintaining cellular integrity, trehalose is known to help human cells respond to environmental stimuli including heat, cold, oxidation, desiccation, etc., by synthesizing stress-responsive components (Rathore *et al.*, 2017). Rich protein-containing mushrooms have all the essential amino acids, with glutamic acid, aspartic acid, and arginine being particularly abundant. In addition to these, the two uncommon amino acids ornithine, which is recognized for its peculiar physiological actions, and Gamma amino butyric acid (GABA), a non-essential amino acid were found (Manzi *et al.*, 1999). In addition, magnesium, phosphorus, calcium, and potassium are abundant in mushrooms. Because they contain comparatively less sodium than other vegetables, mushrooms are considered a good choice for those with hypertension. It has been demonstrated that fresh mushrooms with both soluble and non-soluble fibres, lower total cholesterol, making them advantageous for the treatment of cardiovascular illnesses (Cheung and Lee, 2000). Combining dietary fibre with non-dietary carbohydrates such as β-glucan, polysaccharides-protein complexes (PSPC), chitin, hemicellulose, mannan, xylan, and galactose have several positive effects on human health. In addition to being abundant in volatile compounds, mushrooms also include naturally occurring enzyme systems that have the ability to catabolize aromatic substrates, which may include benzaldehyde, 3-octone, 3-octanol, 1-octen 3-ol, octanol, and 2-octen-1-ol (Cheung and Lee, 2000).

Nutritive value of mushrooms: The nutritional values and compositions of a wide variety of mushroom species are diverse. Common mushrooms are excellent sources of crude protein, multiple essential minerals, complex polysaccharides, fat-free but essential unsaturated fatty acids (>75%), vitamins B (B_2 riboflavin, B_9 folate, B_1 thiamine, B_5 pantothenic acid, and B_3 niacin), and secondary metabolites. They also provide micronutrients and low energy (Alzand *et al.*, 2019). Because of their high antioxidant property in natural functional dietary supplements and bio-therapeutic property, mushrooms are currently gaining increased attention for their potential to alter the immune system and operate as an anti-inflammatory agent (Matsugo *et al.*, 2022). The high percentage of water (85–95%) in raw fresh mushrooms affects their specific heat, a food material attribute required for heat transfer analysis and design procedures (Bell *et al.*, 2022). Vegans abstain from eating animal products and may be deficient in vitamin B_{12}, which is necessary for red blood cell production, mental function, maintenance of the myelin sheath around nerve cells and also involved in the metabolism of fatty and amino acids to generate energy. Compared to plant sources, majority of mushroom species possess vitamin B_{12}. However, the Vitamin B_{12} contents of dried shiitake mushroom fruit bodies significantly varied and the average $VitB_{12}$ was 5.6 micrograms per 100 grams of dried sample (Watanabe *et al.,* 2014).

Probiotic effects of mushrooms: Probiotics have a multitude of mechanisms of action that contribute to their beneficial effects, including resistance to low stomach pH, competitiveness with intestinal microbiota and antagonistic activity against pathogens (e.g., *Salmonella* sp., *Helicobacter pylori*, *Listeria monocytogenes* and *Clostridium difficile*) (Javanmard *et al.,* 2018). *Pleurotus ostreatus, Hericium erinaceus, Coriolus versicolor* and *Lentinus edodes* are the few examples of mushrooms that can effectively alter the composition of the intestinal microbiome by inhibiting the pathogenic bacteria such as *Salmonella, E. coli*, and *Clostridium* and growth enhancement of *Lactobacilli a*nd *Bifidobacteria* (Ferrã *et al.*, 2019). Various components found in mushrooms therefore play an indirect probiotic impact by influencing the microbiota's kind. The β-glucans present in the cell walls of bacteria, fungi, yeasts, algae, lichens and plants serve as a food source for gut bacteria (Scholz-Ahrens *et al.*, 2016).These polysaccharides function as prebiotics and are occasionally employed in herbal medicine, where mushroom β-glucans have several established clinical applications. While, microcins are small protein molecules that are produced by health-promoting gut microorganisms in addition to producing beneficial SCFAs. These molecules retain their biological activity and efficiently enhance health-promoting qualities (Khan *et al.*, 2018).

Edible mushrooms generally possess the medicinal properties which help in supporting longevity, treating many infectious diseases and cancer, moreover medicinal-edible mushrooms also improve the immunological functions of the humans. Some of the preclinical studies suggested that these mushrooms support activation, enhancement and upregulation of NK cells, T cells and induce the induction of immunoregulating cytokines. Immunological properties of medicinal mushrooms are basically due to the presence of many polysaccharides (β-glucans, proteoglycans, and heteroglucans) in the chitin based cell wall of the fungi. Benson *et al.* (2019) studied about medicinally important mushroom *Trametes versicolor* (Tv), commonly called Turkey tail and previously named as *Coriolus versicolor*, which is known to stimulate innate and active immune responses. This mushroom contains the compound which is precursor to the proteoglycans polysaccharide peptide (PSP) and polysaccharide-K (Krestin, PSK), these PSP and PSK are the drugs prescribed for gastric cancer patients in Japan. The fermented substrate produced from rice and Tv mycelia stimulated host defence and immunity. Fermented substrate contains the secreted fungal metabolites mainly cell wall polysaccharides which are in the whole help in the attaining good immune health of an individual (Benson *et al.*, 2019).

Mushrooms due to their nutritional properties also extended their wings to the dairy industry, where *Pleurotus eryngii* an oyster mushroom possess copious bioactive compounds. The polysaccharide secreted from *Pleurotus eryngii* (PEPS) was selected and added as a natural ingredient to the milk before fermentation. The PEPS had considerable effects on bacterial growth, microstructure of milk, texture properties, proteolytic capacity, and angiotensin-I-converting enzyme- inhibitory activities of fermented milk during refrigerated storage (Li and Shah, 2015).

Prebiotic effects of mushrooms: Searching for substitute prebiotic sources is more crucial than before due to recent advancements in the field of prebiotics. With rich carbohydrate contents such as mannans, xylans, chitin, hemicellulose, glucans, and galactans, mushrooms appear to be a promising candidate for prebiotics (Aida *et al.*, 2009). Chitin a polymer which is insoluble in water, amounts to 80-90% of the dry matter found in the cell walls of mushrooms. Veter (2007) stated that chitin is exclusive to some taxonomical groups such as Zygomycetes, Ascomycetes, Basidiomycetes, and Deuteromycetes and is absent in other groups like Oomycetes. The majority of polysaccharides components found in mushrooms are branched and linear glucans with various glycosidic linkages, including (1/3), (1/6)-β-glucans, and (1/3)-α-glucans. While, some of them are real heteroglycans with primary side chain such as arabinose, mannose, fucose, galactose, xylose, glucose, and glucuronic acids, either alone or in varied combinations. Even though the polysaccharides of mushrooms have various chemical compositions, the majority of them are classified as β-glucans (Wasser, 2002).

The non-digestible fibre of edible fungi acts as a substrate for microbial fermentation and interacts with a variety of beneficial gut microbiome. Compared to exogenous β-glucans, endogenous β-glucans exhibit higher level of prebiotic qualities in the regulation of gut microbiota (Taban *et al.,* 2022). Probiotics that produce β-glucan may have the prebiotic ability to promote the development of other advantageous bacteria in the colon. *Pleurotus* sp. has growing data in patents and renewed interest in research and development sector. It is highly evident that probiotic bacterial growth was potential impetus through *Pleurotus ostreatus* and *Pleurotus eryngii* (Bell *et al.,* 2022).

CONCLUSION

Fungi have been utilized in food processing since from many centuries, particularly yeasts and molds, which are used to produce wine, bread, cheese, and a variety of other fermented foods are consumed worldwide. Functions of prebiotics in preserving and enhancing human health have been studied extensively. Prebiotic-containing foods are now widely available in stores as bread, cereal bars, spreads, candies, sauces, baby formula, drinks, and health drinks and many more. Creating a novel potential prebiotic from accessible and affordable resources, such as beneficial molds, yeasts and mushrooms, are something that must be taken into account. Apart from nutritional value, mushrooms extract also possess therapeutic potential. Because of the massive structures, fungal species contribute several advantages, including those related to medicine, the environment, economy, and ecology. Studies indicate that yeasts perhaps function as probiotic microorganisms, despite the fact that the vast majority of research on *Lactobacillus* species, probiotic yeasts are also used as biotherapeutics due to their potential for antibacterial, antioxidant, anticancer, cholesterol 20 absorption, and immunomodulatory activities.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Afolabi, F.T., Adeyemo, S.M., Balogun, H.O. 2018. Fermentation Conditions and Process Optimization of Citric Acid Production by Yeasts. *The International Journal of Biotechnology*, **7:**51-63; doi: 10.18488/journal.57.2018.71.51.63.

Aida, F.M.N.A., Shuhaimi, M., Yazid, M., *et al.*, 2009. Mushroom as a potential source of prebiotics: a review. *Trends in Food Science and Technology,* **20(11-12)**:567-575, doi: 10.1016/j.tifs.2009.07.007.

Alzand, K.I., Bofaris, M.S.M., Ugis, A. 2019. Chemical composition and nutritional value of edible wild growing mushrooms: a review. *World Journal of Pharmaceutical Research*, **8**(3):31-46; doi: 10.20959/wjpr20193-14261.

Andrade, E.F., Lobato, R.V., de Araújo, T.V., *et al.*, 2015. Effect of beta-glucans in the control of blood glucose levels of diabetic patients: A systematic review. *Nutricion Hospitalaria,* **31(1)**:170-7; doi: 10.3305/nh.2015.31.1.7597.

Arévalo-Villena, M., Fernandez-Pacheco, P., Castillo, N., *et al.,* 2018. Probiotic capability in yeasts: Set-up of a screening method. *Lebensmittel-Wissenschaft & Technologie*, **89**: 657-665; doi: 10.1016/j.lwt. 2017.11.047.

Ashraf, S.A., Elkhalifa, A.E.O., Siddiqui, A.J., *et al.*, 2020. Cordycepin for health and wellbeing: A potent bioactive metabolite of an entomopathogenic medicinal fungus Cordyceps with its nutraceutical and therapeutic potential. *Molecules*, **25(12)**:2735; doi: 10.3390/molecules25122735.

Banik, A., Halder, S.K., Ghosh, C., *et al.*, 2019. Fungal probiotics: Opportunity, challenge, and prospects. *Recent Advancement in White Biotechnology Through Fungi: Volume 2: Perspective for Value-Added Products and Environments*, 101-117; doi: 10.1007/978-3-030-14846-1_3.

Bell, V., Silva, C.R.P.G., Guina, J., *et al.*, 2022. Mushrooms as future generation healthy foods. *Frontiers in Nutrition*, **9**:1050099; doi: 10.3389/fnut.2022.1050099.

Belorkar, S.A. (2020). Fungal Production of Prebiotics. In: Fungal Biotechnology and Bioengineering (Eds.: Hesham, A.L., Upadhyay, R., Sharma, G., *et al.*,) Springer, pp.239-254; doi: 10.1007/978-3-030-41870-0_10

Benson, K.F., Stamets, P., Davis, R., *et al.,* 2019. The mycelium of the *Trametes versicolor* (Turkey tail) mushroom and its fermented substrate each show potent and complementary immune activating properties in vitro. *BMC complementary and alternative* *medicine*, **19(1)**:1-14; doi: 10.1186/s12906-019-2681-7.

Bilal, R.M., Hassan, F.U., Saeed, M., *et al.*, 2023. Role of yeast and yeast-derived products as feed additives in broiler nutrition. *Animal Biotechnology*, **34**(2):392-401; doi: 10.1080/10495398.2021.1942028.

Chang, S.T. 1999. Global impact of edible and medicinal mushrooms on human welfare in the 21st century: nongreen revolution. *International journal of medicinal mushrooms*, ***1*(1)**:1-7; doi: 10.1615/IntJMed Mushrooms.v1.i1.10.

Chen, W., Lv, X., Tran, V.T., *et al.*, 2022. From traditional to modern: progress of molds and yeasts in fermented-food production. *Frontiers in Microbiology*, **13**:876872; doi: 10.3389/ fmicb.2022.1075162.

Chang, S.T. 2001. A 40-year journey through bioconversion of lignocellulosic wastes to mushrooms and dietary supplements. *International Journal of Medicinal Mushrooms*, **3(4);** doi: 10.1615/IntJMed Mushr.v3.i4.30.

Chen, X.B., Ding, H.B., Qiao, Y. 2005. Probiotics, immune mechanism and application technology of mannan oligosaccharides. *China Animal Husbandry Veterinary Medicine*, **32**:6-8.

Cheung, P.C. and Lee, M.Y. 2000. Fractionation and characterization of mushroom dietary fiber (nonstarch polysaccharides) as potential nutraceuticals from sclerotia of Pleurotus tuber-regium (Fries) singer. *Journal of Agricultural and Food Chemistry*, **48(8)**: 3148-3151; doi: 10.1021/jf000382s.

Cremon, C., Barbaro, M. R., Ventura, M., *et al.*, 2018. Pre-and probiotic overview. *Current opinion in pharmacology*, **43**:87-92; doi: 10.1016/j.coph.2018.08.010.

Dawood, M.A., Eweedah, N.M., Moustafa, E.M., *et al.*, 2020. Synbiotic effects of *Aspergillus oryzae* and β-glucan on growth and oxidative and immune responses of nile Tilapia, *Oreochromis niloticus*. *Probiotics and antimicrobial proteins*, **12**:172-183; doi: 10.1007/s12602-018-9513-9.

De Oliva-Neto, P., Oliveira, S.S., Zilioli, E., *et al.*, 2016. Yeasts as potential source for prebiotic β-glucan: Role in human nutrition and health. In *Probiotics and prebiotics in human nutrition and health*. IntechOpen; doi: 10.5772/63647.

Del Valle, J.C., Bonadero, M.C., Fernández-Gimenez, A.V. 2023. Saccharomyces cerevisiae as probiotic, prebiotic, synbiotic, postbiotics and parabiotics in aquaculture: An overview. *Aquaculture*, ***569***:739342; doi: 10. 1016/j.aquaculture.2023.739342.

Didari, T., Solki, S., Mozaffari, S., *et al.*, 2014. A systematic review of the safety of probiotics. *Expert Opinon on Drug Safety*, **13**:227-239; doi: 10.1517/14740338.2014.872627.

Doron, S. and Snydman, D.R. 2015. Risk and safety of probiotics. *Clinical Infectious Diseases*, **60** (**Suppl 2**):S129-S134; doi: 10.1093/cid/civ 085.

Evivie, S.E., Huo, G.C., Igene, J.O. 2017. Some current applications, limitations and future perspectives of lactic acid bacteria as probiotics. *Food and Nutrition Research*, **61**:1318034. doi: 10.1080/16546628.2017.131 8034.

Falandysz, J. 2008. Selenium in edible mushrooms. *Journal of Environmental Science and Health Part C*, **26(3)**:256-299; doi: 10.1080/10590500802350086.

Ferrão, J., Bell, V., Chaquisse, E., *et al.*, 2019. The synbiotic role of mushrooms: is germanium a bioactive prebiotic player? A review article. *American Journal of Food Nutrition*, **7(1)**:26-35; doi: 10.12691/ajfn-7-1-5.

Fernández-Pacheco, P., Cueva, C., Arévalo-Villena, M., *et al.*, 2019. *Saccharomyces cerevisiae* and *Hanseniaspora osmophila* `strains as yeast active cultures for potential probiotic applications. *Food & function*, **10(8)**:4924-4931; doi: 10.1039/C9FO00732F.

Fokunang, E.T., Annih, M.G., Abongwa, L.E., *et al.*, 2022. Medicinal mushroom of potential pharmaceutical toxic importance: Contribution in phytotherapy. *IntechOpen*; doi: 10.5772/intechopen.103845.

Ghosh, K., Harikrishnan, R., Mukhopadhyay, A., *et al.*, 2023. Fungi and Actinobacteria: Alternative Probiotics for Sustainable Aquaculture. *Fishes*, **8(12)**:575.

Gibson, G.R., Hollie, M.P., Jan, V. L., *et al.*, 2004. Dietary modulation of the human colonic microbiota: updating the concept of prebiotics. *Nutritional Research Reviews*, **17(2)**:259-275. doi: 10.1079/NRR200479.

Guan, Y., Wang, J., Wu, J., *et al.*, 2017. Enhancing the functional properties of soymilk residues (okara) by solid-state fermentation with *Actinomucor elegans*. *CyTA - Journal of Food*, **15(1)**:155-163; doi: 10.1080/19476337.2016.1226955.

He, L., Duan, Z., Yu, M., *et al.*, 2022. HDA-2-containing complex is required for activation of catalase-3 expression in *Neurospora crassa*. *Molecular biology and Microbiology*, **13(4)**:e01351-22; doi: 10.1128/ mbio.01351-22.

Hoffmann, D.E., Fraser, C.M., Palumbo, F., *et al.*, 2014. Probiotics: achieving a better regulatory fit. *Food and drug law journal*, **69(2)**:237.

Huang, Q., Wei, Y., Lv, Y., *et al.*, 2015. Effect of dietary inulin supplements on growth performance and intestinal immunological parameters of broiler chickens. *Livestock Sci*ence. **180**:172-176; doi: 10.1016/j.livsci.2015.07.015.

Javanmard, A., Ashtari, S., Sabet, B., *et al.*, 2018. Probiotics and their role in gastrointestinal cancers prevention and treatment; an overview. *Gastroenterology and hepatology from bed to bench*, **11(4)**:284.

Jeong, S.Y., Kang, S., Hua, C.S., *et al.*, 2017. Synbiotic effects of β-glucans from cauliflower mushroom and *Lactobacillus* fermentum on metabolic changes and gut microbiome in estrogen-deficient rats. *Genes & nutrition*, **12:**1-12; doi: 10.1186/s12263-017-0585-z.

Julio, P.Z., Francisco, J.R.O., Mercedes, G.L., *et al.*, 2019. Mechanisms of Action of Probiotics. *Advances in nutrition*, **10(Supply-1)**:S49 S66; doi: 10.1093/advances/nmy063.

Khan, A.A., Gani, A., Khanday, F.A., *et al.*, 2018. Biological and pharmaceutical activities of mushroom β-glucan discussed as a potential functional food ingredient. *Bioactive carbohydrates and dietary fibre*, **16:**1-13; doi: 10.1016/j.bcdf.2017.12.002.

Kues, U. and Liu, Y. 2000. Fruiting body production in basidiomycetes. *Application Microbiology and Biotechnology*, **54**:141-152; doi: 10.1007 /s002530000396.

Lai, G.C., Tan, T.G., Pavelka, N. 2019. The mammalian mycobiome: a complex system in a dynamic relationship with the host. *Wiley Interdisciplinary Reviews: Systems Biology and Medicine*, **11(1):**e1438; doi: 10.1002/ wsbm.1438.

Li, S. and Shah, N.P. 2015. Effects of *Pleurotus eryngii* polysaccharides on bacterial growth, texture properties, proteolytic capacity, and angiotensin-I-converting enzyme–inhibitory activities of fermented milk. *Journal of dairy science*, **98(5):**2949-2961; doi: 10.3168/jds .2014-9116.

Liu, L., Li, Q., Yang, Y., *et al.*, 2021. Biological function of short-chain fatty acids and its regulation on intestinal health of poultry [Review]. *Frontiers in Veterinary Science* **8**:736739; doi: 10.3389/fvets.2021.736739.

Manzi, P., Gambelli, L., Marconi, S., *et al.*, 1999. Nutrients in edible mushrooms: an inter-species comparative study. *Food chemistry*, **65(4):**477-482; doi: 10.1016/S03088146(98) 00212-X.

Matsugo, S., Sakamoto, T., Wakame, K., *et al.*, 2022. Mushrooms as a resource for Mibyou-care functional food; the role of basidiomycetes-X (Shirayukidake) and its major components. *Nutraceuticals*, **2(3)**:132-149; doi: 10.3390/nutraceuticals2030010.

Melo-Bolívar, J.F., Ruiz-Pardo, R.Y., Hume, M.E., *et al.*, 2020. Probiotics for cultured freshwater fish. *Microbiology Australia*, **41(2)**:105-108; doi: 10.1071/MA20026.

Nascimento, T.P., Sales, A.E., Porto, T.S., *et al.*, 2017. Purification, biochemical, and structural characterization of a novel fibrinolytic enzyme from *Mucor subtilissimus* UCP 1262. *Bioprocess and Biosystems Engineering*, **40**:1209-1219; doi: 10.1007/s00 449-017-1781-3.

Nash, A.K., Auchtung, T.A., Wong, M.C., *et al.*, 2017. The gut mycobiome of the Human Microbiome Project healthy cohort. *Microbiome*, **5**:1-13; doi: 10.1186/s40168-017-0373-4.

Pandey, K.R., Naik, S.R., Vakil, B.V. 2015. Probiotics, prebiotics and synbiotics-a review. *Journal of food science and technology*, **52**:7577-7587; doi: 10.1007/s13197-015-1921-1.

Pang, Y., Zhang, H., Wen, H., *et al.*, 2022. Yeast probiotic and yeast products in enhancing livestock feeds utilization and performance: An overview. *Journal of Fungi*, **8(11)**:1191; doi: 10.3390/jof8111191.

Maxime, P., Hugot, C., Spatz, M., *et al.*, 2022. "Effects of five filamentous fungi used in food processes on *in vitro* and *in vivo* gut inflammation." *Journal of Fungi*. **8(9):**893; doi: 10.3390/jof8090893.

Polanowska, K., Szwengiel, A., Kuligowski, M., *et al.,* 2020. Degradation of pyrimidine glycosides and L-DOPA in the faba bean by *Rhizopus oligosporus*. *LWT*, **127**:109353; doi: 10.1016/j.lwt.2020.109353.

Rathore, H., Prasad, S., Sharma, S. 2017. Mushroom nutraceuticals for improved nutrition and better human health: A review. *Pharma Nutrition*, **5(2):**35-46; doi: 10.1016/j.phanu.2017.02.001.

Richard, M.L. and Sokol, H. 2019. The gut mycobiota: insights into analysis, environmental interactions and role in gastrointestinal diseases. *Nature Reviews Gastroenterology and Hepatology*, **16(6):**331-345; doi: 10.1038/s41575-019-0121-2.

Rousta, N., Aslan, M., Akbas, M.Y., *et al.*, 2023. Effects of fungal based bioactive compounds on human health. *Critical Reviews in Food Science and Nutrition*, 1-24; doi: 10.1080/10408398.2023.2178379.

Sanchez, C. 2004. Modern aspects of mushroom culture technology. *Applied Microbiology and Biotechnology*, **64**:756-762.

Scholz-Ahrens, K.E., Adolphi, B., Rochat, F., *et al.*, 2016. Effects of probiotics, prebiotics, and synbiotics on mineral metabolism in ovariectomized rats—impact of bacterial mass, intestinal absorptive area and reduction of bone turn-over. *Nfs Journal*, **3:**41-50; doi: 10.1016/j.nfs.2016.03.001.

Sen, S. and Mansell, T.J. 2020. Yeasts as probiotics: Mechanisms, outcomes, and future potential. *Fungal Genetics and Biology*, **137**:103333; doi: 10.1016/j.fgb.2020.103333.

Sharma, C., Osmolovskiy, A., Singh, R. 2021. Microbial fibrinolytic enzymes as anti-thrombotics: production, characterisation and prodigious biopharmaceutical applications. *Pharmaceutics*, **13(11)**:1880; doi: 10.3390/pharmaceutics13111880.

Shirasaka, N., Naitou, M., Okamura, K., *et al.*, 2012. Purification and characterization of a fibrinolytic protease from Aspergillus oryzae KSK-3. *Mycoscience*, **53(5)**:354-364.

Shruthi, B., Deepa, N., Somashekaraiah, R., *et al.*, 2022. Exploring biotechnological and functional characteristics of probiotic yeasts: A review. *Biotechnology Reports*, **34**:00716; doi: 10.1016/j.btre.2022.e00716.

Staniszewski, A. and Kordowska-Wiater, M. 2021. Probiotic and potentially probiotic yeasts—Characteristics and food application. *Foods*, **10(6)**:1306; doi: 10.3390/ foods10061306.

Sugiharto, S. 2019. A review of filamentous fungi in broiler production. *Annals of Agricultural Sciences*, **64(1)**:1-8; doi: 10.1016/j.aoas.2019.05.005.

Szajewska, H., Konarska, Z., Kołodziej, M. 2016. Probiotic bacterial and fungal strains: claims with evidence. *Digestive diseases*, **34(3)**:251-259; doi: 10.1159/000443 359.

Taban, Q., Mumtaz, P.T., Masoodi, K.Z., *et al.*, 2022. Scavenger receptors in host defense: from functional aspects to mode of action. *Cell Communication and Signaling*, **20(1)**:2; doi: 10.1186/s12964-021-00812-0.

Teng, P.Y. and Kim, W.K. 2018. Review: roles of prebiotics in intestinal ecosystem of broilers. *Frontiers in Veterinary Science*, **5**:245; doi: 10.3389/fvets.2018.00245.

Theodoro, S.S., Putarov, T.C., Tiemi, C. 2019. Effects of the solubility of yeast cell wall preparations on their potential prebiotic properties in dogs. *Public Library of Science One*, **14(11)**:0225659; doi: 10.1371/journal.pone.0225659.

Vetter, J. 2007. Chitin content of cultivated mushrooms *Agaricus bisporus*, *Pleurotus ostreatus* and *Lentinula edodes*. *Food*

Chemistry, **102**: 6e9; doi: 10.1016/j.foodchem. 2006.01.037.

Wasser, S.P. 2002. Medicinal mushrooms as a source of antitumor and immunomodulating polysaccharides. *Applied Microbiology and biotechnology*, **60**:258-274; doi: 10.1007/s002 53-002-1076-7.

Watanabe, F., Yabuta, Y., Bito, T., *et al.*, 2014. Vitamin B_{12}-containing plant food sources for vegetarians. *Nutrients*, **6(5)**:1861-1873; doi: 10.1007/s00253-002-1076-7.

Wu, B. and Xu, J. 2011. Antithrombotic effect of a novel protein from *Fusarium* sp. CPCC 480097 in a rat model of artery-vein bypass thrombosis. *Pharmaceutical Biology*, ***50*(7)**: 866-870; doi: 10.3109/13880209.2011.641 023.

Xiao-Lan, L., Lian-Xiang, D., Fu-Ping, L. 2005. Purification and characterization of a novel fibrinolytic enzyme from Rhizopus chinensis 12. *Applied Microbiology and Biotechnology*, **67**:209-214; doi: 10.1007/s002 53-004-1846-5.

Yu, X., Yang, R., Gu, Z., *et al.*, 2014. Anti-tumor and immunostimulatory functions of two feruloyl oligosaccharides produced from wheat bran and fermented by *Aureobasidium pullulans*. *BioResources*, **9(4);** doi: 10.15 376/biores.9.4.6778-6790.

Zhang, C., Zhang, N., Chen, M., *et al.*, 2020. Metabolomics analysis of the effect of glutamic acid on Monacolin K synthesis in Monascus purpureus. *Frontiers in Microbiology*, **11**:610471; doi: 10.3389/fmicb .2020.610471.

Zucko, J., Starcevic, A., Diminic, J., *et al.* 2020. Probiotic–friend or foe?. *Current Opinion in Food Science*, **32**:45-49; doi: 10.1016/j. cofs.2020.01.007.