RECENT ADVANCES ON EFFICACY OF PROBIOTIC YEASTS IN HUMAN WELFARE: AN OVERVIEW

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ARTICLE INFO
Received 31. 7. 2022
Revised 14. 10. 2022
Accepted 3. 11. 2022
Published 1. 12. 2022

Review

ABSTRACT
Due to the enormous benefits for human health, probiotics have gained popularity in the current era of science and have received a lot of public interest recently. Many bacterial strains have been used as probiotics for commercial applications. For a long time, the only yeast, Saccharomyces cerevisiae var. boulardii, was referred to be a probiotic. Interest in the probiotic potential of different yeast strains has grown in recent years. The purpose of the present review is to explore the updated information on the efficacy of various yeast strains as probiotics for human welfare.

Keywords: beneficial effects, efficacy, fermented food, probiotic, yeast

INTRODUCTION
Probiotics are live, non-pathogenic microbes that are crucial for maintaining human health. Yeast has been considered as an important probiotic in human microbiome. Since the 1950s, probiotic yeast (Saccharomyces boulardii) has been available for purchase, and clinical research using it started in 1977 convincingly showed its nonpathogenic nature for safe usage (McFarland, 2010). Mangosteen and lychee fruits were used to isolate Saccharomyces cerevisiae subtype in 1923, which was then dubbed Saccharomyces cerevisiae var. boulardii (Altmann, 2017). This strain could provide better protection against microbial infections as well as toxic compounds which could prevent intestinal epithelial cell damage (Capece et al., 2018). Many studies indicate the potential properties of S. boulardii to treat various GI tract disorders, especially caused by pathogens like Helicobacter pylori, Salmonella, and Clostridium difficile infections (Hudson et al., 2016). A well-known probiotic yeast called S. boulardii has been utilised to treat numerous GI tract illnesses in people (Sen and Mansell, 2020). There is a scope to improve probiotic attributes of S. boulardii using Saccharomyces cerevisiae genetic engineering tools (Pais et al., 2020). S. boulardii's phylogenetic clusters are closely related to strains of S. cerevisiae (Khatri et al., 2017). The prevalence of Saccharomyces strains in the human GI tract is obvious given that S. cerevisiae and other related organisms have been intentionally consumed by humans for thousands of years in the form of bread, beer, and other fermented foods and beverages. However, only a few strains of S. cerevisiae have shown health benefits in humans (Fernandez-Pacheco et al., 2018). Saccharomyces species are well characterized as probiotics and used to treat various disorders (Nash et al., 2017; Sambrani et al., 2021). S. cerevisiae BEL 9 and S. cerevisiae BEL 1 were isolated from lychee fruits which indicated good viability at various stress conditions (Khan et al., 2020). Similarly, S. cerevisiae C41 strain was isolated from Tithos and identified as potential probiotics (Romero-Luna et al., 2019). Saccharomyces cerevisiae isolated from caterpillar frasses showed significant probiotic properties (Khisti et al., 2019). Diatina rugosa 14 and Diatina rugosa 8 were found to have potential as biotechnological probiotics after being isolated from pistachio fruits (Fernández-Pacheco et al., 2021). The advantages of probiotic yeasts include immunomodulation through general gut microbiota maintenance through precise interactions (Lai et al., 2019). Debaryomyces, Candida, Pichia, Candida, Hanseniaspora, Kluyveromyces, and Metschnikowia are known as possible probiotic yeasts. The size of yeasts, which is 10 times bigger than that of bacteria and makes up less than 0.1 percent of the microbiota in the gut, may allow for better coverage of probiotic yeast colonization throughout the GI tract (Hsing et al., 2020). To make fermented foods, yeast strains have been utilized as a starter culture. During this fermentation process, probiotic may produce secondary metabolites viz. fatty acids, esters, acetates and alcohols that gives better aroma to the foods and beverages. This enhances the overall quality of the foods that have undergone fermentation. Nowadays, starter cultures should be made from practically all of the yeast species in the genus Saccharomyces (Arevalo-Villena et al., 2017). According to Agarbati et al. (2020), yeast strains isolated from dairy products and natural habitats were recognized as probiotics from the genera Kluyveromyces, Brettanomyces, Saccharomyces, Rhodotorula, and Pichia. The list of potential probiotic yeasts is constantly being expanded, but S. boulardii is still the only probiotic yeast with a regulatory framework and widespread commercial acceptability. Table 1 shows the list of probiotic yeasts reported by various workers.

Table 1 List of Probiotic yeast strains

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Probiotic yeast</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>S. cerevisiae and S. cerevisiae var. boulardii</td>
<td>Diosma et al., 2014; Gil - Rodriguez et al. 2015</td>
</tr>
<tr>
<td>2.</td>
<td>Cryptococcus spp.</td>
<td>Aloglu et al., 2016</td>
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<tr>
<td>3.</td>
<td>Candida famata</td>
<td>Al - Seraït et al., 2015</td>
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<td>4.</td>
<td>C. tropicalis</td>
<td>Ogunremi et al., 2015</td>
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<td>5.</td>
<td>Debaryomyces hansenii</td>
<td>Ongchago et al., 2016</td>
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<tr>
<td>6.</td>
<td>Issatchenkia orientalis</td>
<td>Ogunremi et al., 2015</td>
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<tr>
<td>7.</td>
<td>Kluyveromyces lactis</td>
<td>Binetti et al., 2013</td>
</tr>
<tr>
<td>8.</td>
<td>Kluyveromyces marxianus</td>
<td>Binetti et al., 2013; Diosma et al., 2014; Smith et al., 2015</td>
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<tr>
<td>9.</td>
<td>Metschnikowia gruessii</td>
<td>Smith et al., 2015</td>
</tr>
<tr>
<td>10.</td>
<td>Pichia jadinii</td>
<td>Buerth et al., 2016</td>
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<tr>
<td>11.</td>
<td>Pichia kluveri</td>
<td>Ogunremi et al., 2015</td>
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<tr>
<td>12.</td>
<td>P. kudriavzevi</td>
<td>Ogunremi et al., 2015</td>
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<tr>
<td>13.</td>
<td>P. pastoris</td>
<td>Correa Franca et al., 2015</td>
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<td>14.</td>
<td>P. guilliermondii</td>
<td>Bonatsou et al., 2015</td>
</tr>
<tr>
<td>15.</td>
<td>Wickeramonymyces anomalous</td>
<td>Bonatsou et al., 2015</td>
</tr>
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</table>

Recently, the use of yeast as a probiotic has received more attention. More research is needed to discover the new yeast species with potential probiotic properties towards the benefit of the human.

References

YEASTS IN FERMENTED FOOD PRODUCTS SHOWING PROBIOTIC POTENTIAL

The probiotic yeast strains Wickerhamomyces anomalous, Nakazawaea molendinii-olei, N. vickerhamii, Yamadazyma terventina, Candida adnataec, and Candida dildensiene have been isolated from a variety of natural sources, including human breast milk, camel raw milk, virgin olive oil, and rotten fruits (apple, grapes, strawberry) and vegetables (cauliflower, brinjal, tomato, cucumber) (Ahmad et al., 2019; Zullo and Ciafa, 2019). Many fermented foods such as yogurt, kimchi, sauerkraut, kombucha, natto, kefir, pickles, tempeh, green olives, miso, cottage cheese and other type of cheeses contain probiotic yeasts. Some of the foods like beer, chocolate, sourdough bread, soy sauce and wine also contain live probiotics. Kluyveromyces lactis, S. unisporus, and S. houardi are probiotic yeasts found in kefir grains (Abraham et al., 2019). Some foods that have a big impact on the health of the host use these helpful bacteria as additives (Lokhande et al., 2019). Figure 1 shows the list of fermented food sources containing yeasts having probiotic potential.

NOVEL CHARACTERISTICS OF PROBIOTIC YEAST

Novel characteristics of probiotic strains include adhesion ability, auto-aggregation, coaggregation, cell surface hydrophobicity, GIT tolerance, cholesterol assimilation, exopolysaccharide production (EPS), production of killer toxins, enzymes, antimicrobial substances, and metabolites.

Figure 1 Probiotic yeasts in various fermented foods

Auto-aggregation and Co-aggregation ability

Aggregation between similar microbes called auto- aggregation and in case of co-aggregation, different strains will adhere together. Probiotic strains with the ability to aggregate improved the development of biofilm to defend the host against pathogen invasion through self-recognition surface components, such as proteins and exopolysaccharides, collectively known as auto agglutinins (Trunk et al., 2018). It was discovered that cell surface hydrophobicity is connected to the capacity to co-aggregate with pathogens (Son et al., 2017).

Five probiotic yeasts, B. custerianus VIT-MN05, S. fibuligera VIT-MN04, L. starkeyi VIT-MN03, K. lactis VIT-MN02, and Y. lipolytica VIT-MN01, were examined utilising in vitro techniques for their potential for adhesion, auto-aggregation and coaggregation, GIT tolerance, and cholesterol assimilation (Ragavan and Das, 2017a). This study showed 92 % auto-aggregation ability for probiotic yeast L. starkeyi VIT-MN03. There are reports on probiotic yeasts such as S. cerevisiae, W. anomalus, Y. lipolytica, and P. barkeri which showed 80% auto-aggregation ability (Suvarna et al., 2018). Yeast strains belonging to Dekkera, Hanseniaspora, Kazachstanula, Kluyveromyces, Kowoniella, Saccharomyces, Saccharomyces, Torulaspora, Wickerhamomyces, and Zygossaccharomyces isolated from kefir milk showed 95% auto-aggregation ability (Hu et al., 2017).

It was discovered that probiotic yeasts can co-aggregate with the pathogens Salmonella sp. and Klebsiella sp. Limosilactobacillus fermentum, a probiotic bacteria, had the highest capacity for co-aggregation, while L. starkeyi VIT-MN03 had capacities of 90% and 92% for co-aggregation of Klebsiella sp., and Salmonella sp. respectively. However, several yeast strains shown high co-aggregation ability (>80%) for both viruses (Ragavan and Das, 2017a). S. cerevisiae LPBF3, a probiotic yeast isolated from honey-based kefir beverage, failed to aggregate with pathogenic E. coli strain and only had a 22% coaggregation ability with S. aureus pathogen (de Oliveira Coelho et al., 2019).

Surface hydrophobicity

The tendency of microbial cells to bind different surfaces (biotic and abiotic) is affected by the hydrophobicity of the cell surface. LAB with strong aggregation abilities has a relatively broad surface hydrophobicity, giving them an added benefit for attachment (Chen et al., 2018). According to percent adhesion values, the degree of hydrophobicity was assigned as strongly (>50 %), moderately (20 % –50 %), and weakly (20 %) hydrophobic (Aziz et al., 2019). Similar to probiotic bacteria P. mirabilis (90 percent), probiotic yeast L. starkeyi VIT-MN03 displayed a high hydrophobicity index (Ragavan and Das, 2017b). Probiotic yeasts including Kluyveromyces marxianus JYC2614, S. cerevisiae, and S. houardi, have been reported to have cell surfaces that are respectively, 68%, 73%, and 86% hydrophobic (Hu et al., 2018; Hsiung et al., 2020).

GIT tolerance

The survival ability of microbes under simulated GIT has generally been considered a key feature in selecting potential probiotics. The probiotic strain should tolerate stomach acid followed by higher concentrations of bile salt in the GIT. This characteristic feature is crucial for maintaining the viability and survival rate of probiotics in a harsh GIT environment (Kizerer-Swida and Binek, 2016). Probiotic yeast strains such as Yarrowia lipolytica, S. cerevisiae, Debaryomyces occidentalis, Debaryomyces Hansenii, and Cryptococcus sp, were reported for better survival at acidic and GIT conditions (El-Baz et al., 2018).

Probiotic yeast Wickerhamomyces anomalous HN1 showed 61.5 % viability and other yeast strains such as Pichia manshurica, Candida tropicalis, and S. cerevisiae, exhibited significant GIT tolerance after 2 h incubation (Helmy et al., 2019). Similar reports were noted for probiotic yeasts S. unisporus and Kluyveromyces lactis (Gut et al., 2019).
Cholesterol assimilation

Numerous mechanisms, such as bile salt hydrolysis activity, the synthesis of inhibitory chemicals, and cholesterol assimilation, are involved in the control of cholesterol (Patience et al., 2004). The yeast strains (Edwards et al., 2013) and Cryptococcus tropicalis (Syal and Vohra, 2017) demonstrated the cholesterol assimilation ability of probiotic yeasts. Probiotic yeast K. lactis VIT-MN02 showed a 90% cholesterol assimilation rate after 24 h of incubation. The probiotic yeasts viz. S. boulardii, P. krudzewitzi, and S. cerevisiae were also reported for cholesterol assimilation which ranges from 1% to >95% (Xu et al., 2012). In the yeast strains Cryptococcus hamiola, Cryptococcus curvatus, Candida kefyr, and S. cerevisiae 832 were noted for increased cholesterol removal (>80%) whereas Monascus purpureus CBS was observed for only 2.75% to 9.27% cholesterol assimilation after 72 hours incubation (Nguyen et al., 2020). Saccharomyces strains showed cholesterol assimilation ranging from 78.52 to 88.97% and non-Saccharomyces strains isolated from milk showed only a 45.7% assimilation rate (Fernández Pacheco et al., 2020).

Exopolysaccharide Production (EPS)

Exopolysaccharides (EPS) are extracellular macromolecules excreted by microbes that form a slimy layer around the cell which helps to bond the cell tightly on the surface of the GIT. Production of EPS from probiotics gained more attention due to its applications as drug delivery, bio-flocculants, and bio-absorbers (Silva et al., 2019). Probiotic EPS are used to treat various human disorders like inflammatory bowel diseases, cardiovascular diseases, obesity, autoimmune diseases, and especially for colon cancer and gastric ulcers (Delgado et al., 2020; Saadaat et al., 2020). S. cerevisiae, Candida sp., and Pichia sp., three probiotic yeasts, have been reported for EPS generation and assist in the manufacturing of food and cosmetic items (Syal and Vohra 2013; Gientka et al., 2016; Yildiran et al., 2019). The probiotic yeast L. starkeyi VIT-MN03 produced six times as much EPS when kept in optimal circumstances utilising the Response surface approach. Probiotic EPS had a flat surface that was good for making films, and it was discovered to be a hetero-polysaccharide (Ragavan and Das, 2019). The highest EPS yield was noted for Candida guilliermondii and Candida famata after optimization of media which ranges from 0.505 and 0.321 129 mg/l respectively (Gientka et al., 2016). Dey et al. (2017) reported the probiotic EPS can be a substantial antimutagenic agent, as shown by its strong binding affinity to the mutagenic compound Glu-P.1. On the generation of EPS by probiotic yeasts, specifically Wickerhamomyces anomalus VIT-ASN01 (586.55 mg/l), S. cerevisiae VIT-ASN03 (464.88 mg/l), and Yarrowia lipolytica VIT-ASN04 (468.72 mg/l). Probiotic EPS also exhibited significant biosurfactant activity compared to xanthan gum. Additionally, probiotic yeast strains’ biosurfactant activity lessens the colonization of harmful bacteria in the stomach (Ragavan and Das, 2019). Similar findings about their potential qualities were reported for P. kluyveri and S. cerevisiae (Yildiran et al., 2019). - Glucan is a yeast by-product with a number of beneficial health effects. The cell walls of many eukaryotic species include a polymer of -(1,3)-D-glucose polysaccharides. S. cerevisiae’s cell wall is composed of mannanproteins, -(1,3)-D-glucan, and -(1,6)-D-glucan. The activation of macrophages’ non-specific immunological response and stimulation of cell growth are two ways that -glucan is known to have positive effects on health (Kang et al., 2014).

Production of Killer toxin

Proteins known as killer toxins bind to particular receptors on the surface of microbial cells. The killer toxin production from yeast species has been well characterized in many studies to prevent spoilage of food products from pathogens (Mannazzu et al., 2019). Killer activity by probiotic yeast Kluyveromyces lactis VIT-MN02 against food-borne pathogens was reported at optimized conditions (pH 3 at 25°C with 0.5% NaCl) (Ragavan and Das, 2020a). According to reports, the yeast strains Kluveromyces sp., W. saturnus, P. anomala, and Saccharomyces cerevisiae produced killer toxin that had similar killing effects on infections (Golubev, 2013). The killer toxin was discovered to be 22 kDa (K2), 18 kDa (K3), and 14 kDa (K4) in size. These findings revealed that probiotic yeasts could produce killer toxins to stop bacterial contamination during fermentation (Menehghin et al., 2010). The shelf lifequality of the food products is ensured by the antimicrobial protein made by the yeast Metschnikowia pulcherrima, which also dramatically decreased the spoiling of ready-to-cook ground beef patties (Bedir and Kuleaşan, 2021). It was discovered that the pathogenic yeast Filobasidiella neoformans was resistant to the killer toxin produced by Cryptococcus pinus VKM Y-2598 (Kulakowskaya et al., 2019). The killer toxin activity of probiotic yeast strains from the species Saccharomyces cerevisiae, Candida tropicalis, Candida pintoipolites, and S. cerevisiae against Cryptococcus neoformans has been demonstrated (Dubash et al., 2010).

Production of enzymes

Screening for the production of enzymes is the most important criteria for selecting probiotic strain. The enzymes such as β-glucuronidase, β-glucosidase and N-acetyl-b-glucosaminidase are considered as harmful enzymes. These enzymes are associated with GIT diseases and have been reported in some studies. Therefore, care should be taken for selecting probiotic strain producing harmful enzymes. On the other hand, some enzymes, such β-galactosidases and -glucosidase, are said to benefit the host. In its treatment of lactose intolerance, β-galactosidases have demonstrated strong activity. Another enzyme, -glucosidase helps to digest polysaccharide compounds to exert its beneficial effects in the GIT (Aitz et al., 2019). The probiotic yeasts viz. Cryptococcus gaveucis, Leuconecoraopora sp. produce cellulase enzyme which was reported by Carrascos et al. (2016). Catalase, S. cerevisiae, K. lactis, and L. lactis are known that give the first line of defence to the host system. The significant catalase activity observed in probiotic yeasts Y. lipolytica and S. cerevisiae was reported by Czech et al. (2020). Acute lymphoblastic leukaemia and Non-Hodgkin lymphoma (NHL) were two tumours that L-asparaginase was thought to be a promising chemotherapeutic drug to treat. By inhibiting the leukemic glycolysis, L-asparaginase may also provide a potential role in the food sector in preserving the quality of food. Ragavan and Das (2020b) reported two probiotic yeast isolates which showed catalase and L-asparaginase activity.

Production of antimicrobial substances

Antimicrobial substances produced by probiotics are the best replacement for chemical preservatives which can improve the quality of food products. The probiotic yeast isolates showed remarkable antimicrobial activity against common pathogens (Ragavan and Das, 2017a). Probiotic yeast substantial antibiotic efficacy against common human infections such as Enterococcus faecalis, E. coli, S. aureus, Pseudomonas aeruginosa, and Listeria monocytogenes was demonstrated by S. cerevisiae and S. boulardii (Rajkowska et al., 2012). Another benefit of S. cerevisiae var. boulardii may be its antimicrobial properties and capacity to degrade mycoxotins such as ochratoxin A patulin, and aflatoxins, (Abdel-Kareem et al., 2019; Liu et al., 2020). Additionally, Staphylococcus aureus, Pseudomonas aeruginosa, E. coli and Bacillus subtilis growth is inhibited by antimicrobial peptides derived from S. cerevisiae var. boulardii (Naimah et al., 2018). A typical food-borne infection that causes diarrhea is ETEC (Enterotoxogenic E. coli). The main pathogenicity of bacteria is the production of adhesins and enterotoxins. S. cerevisiae significantly reduced ETEC growth and toxin generation. The yeast also decreased bacterial adhesion to intestinal Caco-2/TC7 cells. In addition, S. cerevisiae reduced the generation of interleukin-8 which is produced by ETEC-infected intestinal cells (Roussel et al., 2018).

Metabolites produced by probiotic yeasts

Probiotics have a number of effects, including as preventing pathogen colonization or adhesion, generating metabolites, and modifying the immune system by creating immunoglobulin antibodies (Chugh and Kamal-Eldin, 2020). The development and establishment of advantageous microorganisms in the stomach may result in the production of thiamine, folate, propionic acid, folate, and vitamin B12 (Piwowarek et al., 2019). B vitamins including B1, B2, B5, B6, and B12 as well as ergosterol, which can be converted to vitamin D2, can all be found in probiotic yeasts. For vitamin B complex, S. cerevisiae Pichia membranaefaciens, Pichia fermentans, and were reported (Silva et al., 2011). Zinc, magnesium, phosphate, iron and absorption in vertebrates are encouraged by the group of fat-soluble chemical known as calciferol (vitamin D). In relation to irradiation of S. cerevisiae was used to stimulate the conversion of yeast sterol to ergocalciferol for use as a dietary supplement (Amiri et al., 2019). Vitamin A is a necessary human vitamin that aids eyesight, reproduction, immune function, and skin health. Engineered probiotic yeast Saccharomyces cerevisiae was reported for synthesis of vitamin A (Sun et al., 2019).

In order to stop dangerous microbe adhesion and invasion, probiotics can also change mucin development and the colon’s barrier function. Successful probiotics, like S. boulardii, should be able to adhere to the intestinal mucous, whereas epithelial cells make mucin to prevent pathogenic bacteria from attaching to them (Edwards-Ingram et al., 2004). The amount of accessible pathogen binding sites is decreased as a result of S. boulardii's attachment to the mucus membrane. The infections’ capacity to connect directly to intestinal receptors and continue with host invasion is constrained by this interaction.

HEALTH BENEFITS ENDED BY PROBIOTIC YEAST

Probiotic yeast S. boulardii has various beneficial properties to maintain host health (Figure 2). Probiotic yeast strains were reported for their therapeutic properties to maintain gut microbiota from harsh environmental conditions as well as pathogen colonization (Table 2). By producing trophic polyamines or other enzymes, such as alkaline phosphatase, -glucosidase, maltase-glucosamylase, lactase, and sucrose-isomaltase, probiotic yeast S. boulardii promotes improves nutritional absorption and enterocyte maturation (Moslehi-Jenabian et al., 2010). Other crucial advantages of probiotic yeasts include enhancing dietary intake, boosting the immune system, preventing GI illnesses, lowering blood cholesterol levels and significantly reducing the chance of colon cancer (Saberr et al., 2017). Key metabolic pathways that regulate metastasis, angiogenesis, inflammation, apoptosis, differentiation, and cell proliferation have been
demonstrated to interact with probiotics and their metabolites. Probiotics also affect the function of GI enzymes, prevent pre-cancerous lesions and suppress carcinogenic elements both in vitro and in vivo (Cousin et al., 2012; Kumar et al., 2013). One of the leading causes of cancer-related morbidity and mortality in people is colon cancer (Bocci et al., 2015). On Caco-2 cell line as opposed to IEC-6 cell line, probiotic yeast showed considerable anticancer action. K. lactis VIT-MN02, in particular, demonstrated 75% anticancer efficacy on Caco-2 cells. Therefore, K. lactis VIT-MN02, a probiotic yeast, can be utilized to lower the risk of colon cancer. Type 2 diabetes is linked to enzymes like -glucosidase and -amylase. The enzyme -glucosidase is inhibited by K. lactis VIT-MN02 (Ragavan and Das, 2020b). Hyperglycemia and type 2 diabetes mellitus could both be avoided by inhibiting a-amylose activity (Ayyash et al., 2018). The a-amylose enzyme was inhibited by L. starkeyi VIT-MN03. As a result, this research demonstrated that the probiotic yeasts L. starkeyi VIT-MN03 and K. lactis VIT-MN02 can be utilized to maintain or regulate blood sugar levels in humans. Another study found that S. cerevisiae stimulated lipoxygenase necrosis, and ischemia (coagulative), apoptosis, and tumor degeneration in Swiss albino mice with Ehrlich ascites carcinoma (EAC) (Ghoneum et al., 2008). The probiotic K. marxianus AS41 isolated from dairy products influences metabolic activity and has pro-apoptotic activity in epithelial cancer cells without affecting normal cells (Saber et al., 2017). By inhibiting the mTOR, JAK-1 and AKT-1 pathways, exopolysaccharides produced by Pichia kudriavzevii and Kluyveromyces marxianus cause apoptosis in many colon cancer cell lines (Saadat et al., 2020). In the treatment of colorectal cancer, probiotic yeasts such Metschnikowia, Hanseniaspora, Pichia, Debaryomyces, Candida, Kluyveromyces and S. cerevisiae var. boulardii may have anti-cancer characteristics (Sambrani et al., 2021). However, it must pass human clinical studies in order to be licenced.

Yeast is a best model organism to investigate the antioxidant activities which has potential industrial applications (Meng et al., 2017). P. fermentans S. cerevisiae sp. and were found to have antioxidant properties, suggesting that probiotic yeasts can effectively reduce cellular damage caused by oxidative stress (Chen et al., 2010; Hassan 2011; Sourabh et al., 2011). Probiotic yeast L. starkeyi VITMN03 showed 76% DPPH activity (Ragavan and Das, 2020b) whereas 12 strains from S. cerevisiae showed only 42% DPPH activity (de Lima et al., 2017). Recently, highest antioxidant activity was observed by Prototheca wickerhamii 1885 (83%), whereas reference strain S. boulardii showed only 70% antioxidant activity (Ciafardini and Zullo, 2020). There are reports on probiotic mediated antioxidant activity namely, free radical scavenging activities and H2O2-induced stress in GIT which may prevent oxidative damage to maintain host health (Son et al., 2017; Tang et al., 2017). The probiotic yeast S. fibuligera VIT-MN04 showed more resistance to H2O2 up to 86% than other yeasts which could ensure the viability of probiotics during H2O2 induced stress conditions. Moreover, probiotic yeast K. lactis exhibited 70% hydroxyl radical scavenging activity (Ragavan and Das, 2020b).

Table 2 Therapeutic properties of probiotic yeasts

<table>
<thead>
<tr>
<th>Probiotic yeasts</th>
<th>Therapeutic properties</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saccharomyces boulardii</td>
<td>Prevents Salmonella &amp; E. coli infection</td>
<td>Buts et al., 2006</td>
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<tr>
<td></td>
<td>Inhibition of toxin production by pathogens like V. cholerae, C. difficile and C. perfringens</td>
<td>Czerucka et al., 2007</td>
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<tr>
<td>Candida krusei</td>
<td>The killer toxin produced by yeast inhibited the growth of pathogenic bacteria such as</td>
<td>Soyturk et al., 2012</td>
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<td></td>
<td>S. Typhimurium, S. aureus and Bacillus cereus</td>
<td>Ochigava et al., 2011</td>
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<tr>
<td>Pichia rhodanensis</td>
<td>Production of antibodies and human membrane proteins</td>
<td>Goncalves et al., 2013</td>
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<tr>
<td>Torulaspora delbrueckii, Kluyveromyces lactic and Pichia pastoris</td>
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<tr>
<td>Pichia kudriavzevii RY55</td>
<td>Mycocins inhibited the growth of pathogens like Enterococcus faecalis, Klebsiella sp., S. aureus, H. pylori eradication</td>
<td>Bajaj et al., 2013</td>
</tr>
<tr>
<td>Saccharomyces boulardii</td>
<td>(Neuraminidase from S. boulardii removes surface α(2,3)- linked Sialic acid, which is the substrate for H. pylori adhesion)</td>
<td>Sakarya and Gunay 2014</td>
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<td></td>
<td>Inhibition of chlorine secretion during Rotavirus Diarrhea</td>
<td>Bucigrosi et al., 2014</td>
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<td></td>
<td>Reduced Pro-inflammatory cytokines (IL-8 and TNFα) and increased anti-inflammatory cytokines (IL10) in blood</td>
<td>Abbas et al., 2014</td>
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<td></td>
<td>Reduced cholesterol and uric acid levels</td>
<td>Costanza et al., 2015</td>
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<td>S. cerevisiae UFMG A-905 and S. boulardii</td>
<td>Immunomodulatory properties through reduction of inflammation and IL-6, TNF-α, Interferon gamma (IFN-γ) and IL-10 production</td>
<td>Palma et al., 2015</td>
</tr>
<tr>
<td>Kluyveromyces marxianus &amp; Metschnikowia gruessii</td>
<td>Protection and maintenance of epithelial barrier integrity</td>
<td>Smith et al., 2015</td>
</tr>
<tr>
<td>Saccharomyces cerevisiae</td>
<td>Reduced collic tissue damage, TNFα protein expression, NF-kB phosphorylation and actin disruption</td>
<td>Koon et al., 2016</td>
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<td></td>
<td>caused by C. difficile-associated infection</td>
<td>Sambrani et al., 2021</td>
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<tr>
<td>Saccharomyces cerevisiae</td>
<td>Inhibition of tumor cell proliferation</td>
<td></td>
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<tr>
<td>Saccharomyces candida</td>
<td>Antagonistic activity against S. typhimurium demonstrated using intestinal cell lines</td>
<td>Ragavan and Das 2020b</td>
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<tr>
<td></td>
<td>Production of vanillic acid, cinnamic acid, phenyl ethyl alcohol (rose oil), erythromycin, amphetamine and vitamin B6 to exert beneficial effects in host</td>
<td>Datta et al., 2017</td>
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<tr>
<td>Saccharomyces cerevisiae var. boulardii</td>
<td>Antifungal activity against moulds species like A. flavus, A. niger, P. expansum, P. carneum, P. spinulosum and P. rubens</td>
<td>Nag et al., 2022</td>
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<tr>
<td>Saccharomyces cerevisiae</td>
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<td>Goktas et al., 2021</td>
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Figure 2 Health benefits of probiotic yeast Saccharomyces boulardii

CONCLUSION

The benefits of probiotic yeasts isolated from various conventionally fermented foods as well as the potential use of these organisms in probiotic products have been studied by the scientific community. More than a decade has been passed on the exploration of the efficacy of probiotic yeast having therapeutic properties for human welfare. Extensive studies have been conducted to fill up the gap between what we know about the important activities of probiotic yeast towards the health benefits. More information has been covered in the field of yeast probiotics by exploiting accumulated knowledge underlying the novel characteristics and other
technological advances as discussed in this review. In order to ensure therapeutic advancement, safety, and the quality of highly consumed probiotic foods containing probiotic yeasts for food and human welfare, scientists can use this knowledge at the research and industrial level to re-engineer the goods.

**Conflict of interest:** None to be declared

**REFERENCES**


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