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Yeast Mannan: Structure, Extraction and Bioactivity

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Abstract

Background and Objective: Yeasts are cheap and easily available sources of valuable bioactive compounds such as mannan. Spend yeasts as byproducts of various industries can be used to extract mannan, making the production process economical. Various factors such as growth conditions and cultivation system affect cell wall structure of the yeasts. The most common use of yeast mannan is as a prebiotic in animal feed. Its metabolism in the intestinal cell wall can produce postbiotic compounds such as short-chain fatty acids. Extraction of mannan has not been reported as a known classical method, depending on its final use and costs. The most popular cost-effective method is the acid-alkaline strategy. The current article has reviewed all aspects of structure, methods of extraction and recent studies on potential uses and bioactivities of yeast mannan and mannooligosaccharides, including modulation of animal gut microbiome, immune system and animal performance, as well as its antioxidant activity.

Results and Conclusion: Literature review shows that mannan, manno-oligosaccharides, mannan rich fraction and their combination with probiotics and/or other bioactive compounds such as β-glucan may modulate compositions of gut microbiota. Various studies have shown that effectiveness of mannan depends on the species of animals and their age, diet, environmental conditions and rearing system. By optimizing the growth and cultivation conditions of yeasts, it is possible to increase proportions of mannan in the cell wall of yeasts, increasing efficiency of the industrial production. Although the most widely used yeast in industries is *Saccharomyces cerevisiae*, other *Saccharomyces* strains (e.g., *Saccharomyces boulardii*) and non-*Saccharomyces* yeasts (e.g., *Pichia* and *Kluyveromyces* spp.) can also be considered as high yielding strains.

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1. Introduction

In recent years, indiscriminate use of antibiotics in livestock and poultry feed has been a serious threat for the global health. With increasing public awareness, researchers have focused on replacing chemicals with bioactive compounds derived from plants, bacteria and fungi worldwide. Yeasts are sources of valuable bioactive compound like mannan interested by biotechnologists for use in various industries. Mannan is detected in the structure of plants [1] as well as cell wall of yeasts [2], fungi [3] and bacteria [4].

Yeasts are surrounded by a wall that constitutes 20-25% of dry mass of the cell and is responsible for providing osmotic and physical protections and determining cell shape [5]. Mannan, β-glucan and chitin are the major components of the cell wall [2]. Ratios of these components vary significantly based on the microbial strain and growth condition and stage [6]. Mannan is water-soluble compound that comprises 35-40% of the cell wall of *Saccharomyces* (*S.*) *cerevisiae*, which is always used as a classic model microorganism in yeast cell wall investigations. Mannans in the yeast cell wall are in the form of mannoprotein, which consists of a highly branched polysaccharide of mannose that is attached to proteins [5]. Mannooligosaccharides (MOS) are nondigestible oligosa-ccharides composed of short mannose chains [3-10].

They are achieved through partial hydrolysis of mannan polysaccharide [7].

Yeasts are cheap and available sources of mannan. Mannan constitutes a significant proportion of yeast cell wall; hence, its extraction from yeasts is cost-effective and economically justified. Mannan is extracted from the yeast cell wall in three major steps of yeast cell lysis and fractionation and purification of the resulting mannan fractions. Each of these steps can be carried out using various methods [8]. Purity and efficiency of the final products depend on the selected methods. The MOS production is carried out using chemical (selective acetolysis, acid or alkaline hydrolysis and combination of methods) and enzymatic methods [9]. Studies have reported health-promoting activities for mannan and MOS such as prebiotic properties by selectively stimulate growth of bacteria and suppressing pathogens [10], immunomodulatory properties [11] and antioxidant activities [12]. Mannan, similar to antibiotics added to the feed, is able to change microbial population in the intestinal tract; hence, it has widely become an alternative to antibiotics [8]. The aim of the present study was to review the current knowledge about yeast mannan and MOS, focusing on the structure, extraction processes, biological activities and potential uses.

2. Structure

Mannan includes long polysaccharide chains consisting of mannose (nearly 90%) linked to protein (10%), which is located in the outer layer of the yeast cell wall. In the main chain, mannose residues are connected with α (1→6) glycosidic bonds. In the side chains, mannose molecules are connected to the main chain through α (1→2) and α(1→3) linkages (Figure 1). Carbohydrate moiety can be attached to the hydroxyl group on a serine or threonine (*O*-linked) or the amine of an asparagine (*N*-linked) [2]. Proteins limit the permeability of the cell wall against enzymes and interfere foreign compounds [5]. Electron microscopy (EM) studies of the cell wall structure of *S. cerevisiae*, which is a classic model for biology and biotechnology studies, have revealed that the budding *S. cerevisiae* includes a bi-layered structure. Inner part of the wall, which is electron transparent, is majorly composed of branched 1,3-glucan that are linked by hydrogen bonds and covalently bonded with 1,6-glucan and chitin. Mannoproteins are located in the outer part of the wall, which is the electron-dense part. They bind to the yeast cell wall in three ways of covalent, non-covalent bonding with structural glucan and disulfide with proteins covalently attached to the cell wall [5,13].

Mannan is one of the major constituent groups of the hemicellulose structure in the cell wall of higher plants, which are found in the form of pure mannan and heteromannan (glumannan, galactomannan and galactogluco mannan). In pure mannan, there are linear structures of mannose units linked by β (1→4) glycoside bonds, while heterogenous mannan includes a combination of glucose and mannose (glucomannan), galactose and mannose (galacto-mannan) or galactose, glucose and mannose (galactogluco-mannan) [1]. Plant-derived mannan has been commercial-ized in gums form such as guar and locust bean gums. It is used in food, biomedical, pharmaceutical and textile industries due to their physicochemical characteristics such as solubility in water, viscosity, biodegradability and stability in aqueous solution [14,15]. Moreover, mannan has been identified in the structure of compounds produced by Gram-negative and Gram-positive bacteria. Dolfi et al. [16] isolated a novel rhamno-mannan exopolysaccharide from biofilms of a strain of *Burkholderia multivorans* (Gram-negative bacteria). In another study, mannan exopoly-saccharide production was reported for the first time from *Weissella confuse* (Gram-positive bacteria). Investigating physicochemical properties of this compound revealed that it could be used in functional foods to improve rheological characteristics and mouth feel and increase food shelf life [4].

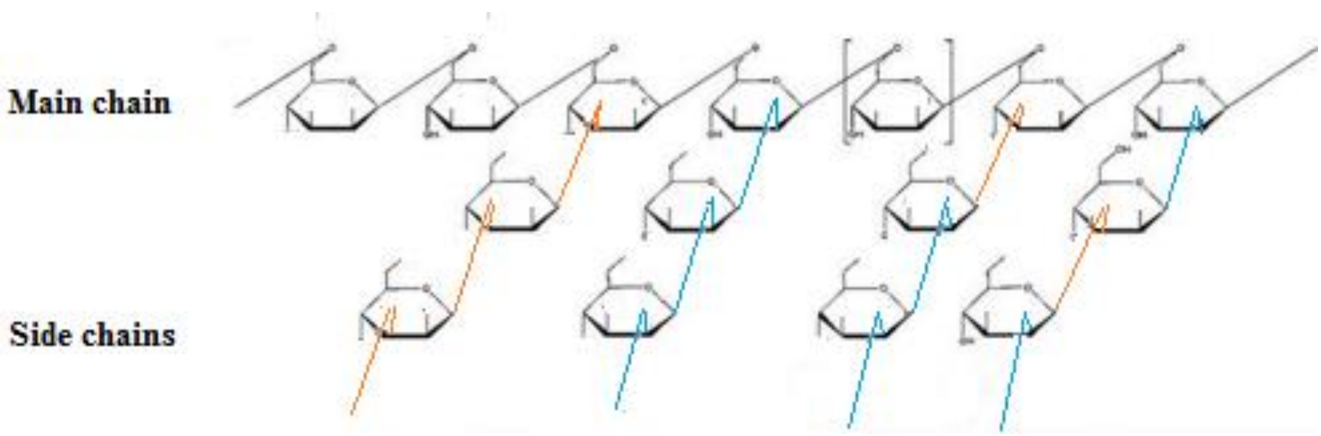

Figure 1. Structure model of the yeast mannan. Units of mannose are present in parenthesis. Main chain, α-(1 → 6)-mannan; side chain, red connections include α-(1 → 3)-mannan and blue connections include α-(1 → 2)-mannan

2.1. Factors affecting mannan production

Formation of cell wall polysaccharide-protein complexes strongly depends on external conditions such as growth conditions (e.g., carbon source, pH, aeration and temperature) and mode of cultivation [17]. In a study [18], mannan production by *Kluyveromyces marxianus* with four variables, including concentrations of carbon source (15, 30 and 45 g.l^{-1}), glycerol and methanol (0, 2.5 and 5 g l^{-1}) and nitrogen source (yeast extract and peptone 4, 6 and 8 g l^{-1}), as well as fermentation time (48, 96 and 144 h), pH (4, 6 and 8) and agitation speed (150, 200 and 250 rpm), were optimized. Results showed appropriate conditions for mannan production by *K. marxianus* as 55.15 gl^{-1} glucose, 9.35 gl^{-1} yeast extract, pH 4.99 and fermentation time of 168 h, which resulted in a mannan yield of 245.98 mg (100 ml)$^{-1}$ culture media. In another study [19], waste potato juice water and glycerol were used as sources of carbon, nitrogen and mineral components in culture media of *Saccharomyces* strains and their effects on biosynthesis of mannan cell wall polysaccharides were assessed. The study reported that deproteinated potato juice water supplemented with 15-25% of glycerol with initial pH values of 4 and 5 increased mannoprotein in the cell wall structure of three of the four strains. Structure of the mannonprotein layer of the strains cultured in media with 20-25% glycerol varied, which could be resulted from changes in polymerization ratio, branching, composition and spatial organization of the mannoprotein molecules. In assessing effects of various factors on yeast mannan production by Hanneh et al. [20], it was verified that temperature, initial pH and inoculum size were respectively effective on mannan production.

3. Extraction

Mannan extraction usually involves yeast cell lysis, separation and fractionation of mannoproteins and mannan purification. Cell lysis is a critical step in the yield of the product; therefore, this step has been studied more than that the other steps have [8]. Cell lysis via physical methods (e.g., bead milling, high pressure homogenization, ultrasonication and radiation), chemical methods (e.g., hot alkaline method, acid-alkaline method and buffer solutions such as sodium phosphate, citrate or tris and detergents), enzymatic methods (e.g., proteases, glucanases and carbohydrases) or a combination of these methods can be used [21,22]. Ethanol, methanol and acetone are used for mannan recovery [23,24]. Degrees of purity of the final product determines the quality of the extraction steps. Common purification methods include chromatography (e.g., affinity chromatography and size exclusion chromatography) and ultrafiltration [25,26]. Mannan rich fraction (MRF) is produced under controlled enzymatic, chemical or a combination of these methods and contains unwanted sugar and non-sugar compounds that can be removed by purification [27].

The MOS production includes chemical and enzymatic methods. Of the chemical methods, selective acetolysis and acid and/or alkaline hydrolysis can be addressed. Enzymatic methods are highly selective; however, they are expensive. In the selective acetolysis, toxic compounds such as pyridine and sodium methoxide are used to produce MOS. From the methods, acid and alkaline methods are further popular despite being less selective because they are cost-effective and do not use toxic substances [8].

To decrease costs and increase efficiency in extraction and recovery of mannan, a combination of various methods is usually used based on the use of the final product. However, no standardized methods are available. The more the number of steps needed for the purification, the purer the final product with a lower yield. Faustino et al. [22] investigated effects of various extraction methods (alkaline thermal process, autolysis followed by a hydrothermal step and enzymatic hydrolysis) on the structural, physicochemical and

Biological characteristics of mannan. In addition, the process yields and costs were assessed. They reported that autolysis followed by a hydrothermal step was the most cost-effective extraction process, resulting in the highest mannose content (59.19%). The highest prebiotic activity was reported in the extract achieved through enzymatic hydrolysis; however, it was the most expensive method. Alkaline hydrolysis resulted in high yields (0.25 M NaOH); thus, the mannose content was low. In another study [28], effectiveness of a combination of mechanical and enzymatic methods on mannoprotein extraction was assessed in four strains of *Saccharomyces* and non-*Saccharomyces* yeasts (*S. cerevisiae*, *S. boulardii*, *Metschnikowia fructicola* and *Torulaspora delbrueckii*). Yeast cells treated with 80% of the maximum possible ultrasound amplitude, duty cycle of 50% within 4 min followed by an enzymatic treatment of 4000 U of lyticase from *Arthrobacter luteus* (β-1,3-glucanase) per gram of dry cell weight showed the highest mannoprotein-rich yield of all strains. Furthermore, it was shown that the use of ultrasound treatment followed by 20-h incubation with lyticase on various yeast species resulted in the highest concentration of carbohydrates and proteins.

Galinari et al. [29] extracted cell wall mannan of *K. marxianus* with 3% NaOH at 80 ◦C for 6 h. Centrifugation (9800 g for 10 min at 4 ◦C) was carried out to remove cell debris. The pH of the supernatant was adjusted to 7 using HCl (4 mol l^{-1}). Mannan was precipitated with methanol for 12 h and recovered by centrifugation (15,300 g for 30 min at 4 ◦C). In a similar study by Liu and Huang [30], mannan was extracted from yeast cell wall under conditions of 100 °C, 2 h, 1% NaOH and 10:1 solid:liquid ratio. After centrifugation, pH of the supernatant was adjusted to 3 using HCl. Then, mannan was precipitated using ethanol. Purity of the extracted mannan included 96.15%. In a study on the biological characteristics of yeast mannan, Oba et al. [31,32]

extracted mannan based on a method described in Patent JP4979924 [33]. Briefly, slurry of yeast cell wall was prepared and washed under alkaline condition to remove Proteins and amino acids. Washed slurry was subjected to hot alkaline extraction. The extracted yeast cell wall was centrifuged to collect a light-phase liquid as the yeast mannan fraction. After alkaline hydrolysis, slurry was heated under acidic condition to separate the insoluble products via heat coagulation. Fraction was filtered, neutralized, sterilized and spray-dried. Mannan concentration was 53%, calculated based on the mannose concentration. Wan et al. [34] showed that the mannan extract recovery rate prepared by the thermal method was significantly higher (35.89%) than those achieved using fermentation and SDS treatment. Due to the functional properties of β-glucan and mannan, their simultaneous extraction has been described in patents based

On various methods [35,36]. Furthermore, a combination of mannan and β-glucan has been commercialized by companies. Simultaneous extraction of these two compounds can decrease downstream purification processes and therefore production costs.

4. Bioactivities

So far, the biological activity of yeast mannan has been determined *in vivo* and *in vitro*, indicating potentials of its use in pharmaceutical and animal feed. Some of these studies are summarized in Table 1. Various studies have demonstrated prebiotic effects of MOS by creating balanced microbiomes despite changes in intestinal pH [37]. Several commercial products with specific biological activities are available as feed additives in the market [38].

4.1 Modulation of animal gut microbiome

Studies have shown that dietary administration of mannan, MRF, MOS and their combination with probiotics or bioactive compounds such as β-glucan includes positive effects on animal health by modulating gut microbiome compositions. Antipathogenic activity of mannan is exerted by its binding to lectin on the surface of pathogens and preventing adhesion of lectin to intestinal wall and further microbial colonization (Figure 2). Mannan metabolism in intestinal cell wall can cause production of postbiotic compounds such as short-chain fatty acids that include significant effects on the function of intestine and hence health of the host [49,50].

Leigh et al. [51] investigated effects of MRF supplementation on microbiome diversity and composition of the intestinum tenue and cecum of the commercial broilers. Supplemented birds included lower levels of *Escherichia coli* and *Clostridioides difficile* within the three intestinum tenue sites. Probiotic genera (such as *Lactobacillus* and *Blavetia*), SCFA synthesizing bacteria and SCFA concentrations were higher in birds fed MRF supplements.

Table 1. Biological activities of the yeast mannan alone and in combination with other compounds in animal models

Composition	Animal model	Bioactivity	Reference
Mannan rich fraction	Fish	-Bolstering the skin barrier and Immune functions -Lower susceptibility to sea lice	[39]
Mannan oligosaccharide ,live yeast and organic selenium	Beef cattle	-Improving immune systems, growth performances and feed efficiency -Ability to react against pathogens	[40]
Mannan and probiotics	Lamb	-Potentiate positive effects on digestion and ruminal fermentation	[41]
Mannan oligosaccharide and β-glucan	Broiler chickens	-Improving growth performance and intestinal morphology -Increasing body weight gain	[42]
Mannan oligosaccharide	Fish	Improving the liver health	[43]
Mannan oligosaccharide	Fish	-Increasing the relative abundance of beneficial gut microbiota -Immune protective effects	[44]
Mannan and β-glucan	Beef cattle	-Enhancing immunocompetence and productivity	[45]
Mannan oligosaccharide	Lobster	-Improving growth performance survival, physiological condition -Gut health and immune responses	[46]
Mannan oligosaccharide and inulin	Shrimp	-Enhancing innate immune response -Pathogen resistance	[47]
Yeast cell wall	Hen	-productive performance -Improving the internal and external egg quality -Contributing to greater profitability	[48]

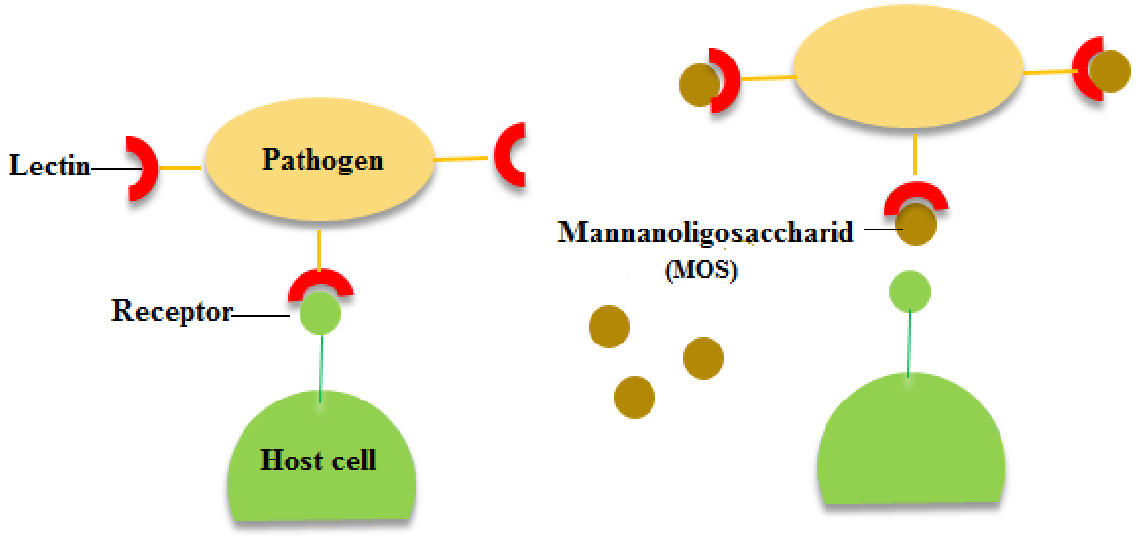

Figure 2. Potential mechanisms of the antipathogenic activity of mannan

In a study of Zampiga et al. [52], dietary supplementation of the fraction rich in MOS and β-glucan improved fecal microbiome composition of turkeys, which promoted healthy gut conditions. After adjusting supplementation levels, a better feed efficiency was observed. Sergij et al. [53] showed the ability of MRF isolated from the cell walls of *S. cerevisiae* to adsorb *Salmonella enteritidis* and *Campylobacter jejun*. *In vivo* studies on activity, colonization and species composition of duck intestinal microflora demonstrated that re-isolation rate of *S. enteritidis* and *C. jejuni* in ducks receiving MRF decreased by 53.6 and 66.2%, respectively. In addition, a combination of *Bifidobacterium* spp. (1.5×10^9 CFU ml^{-1}) and MRF (0.4 kg t^{-1}) during growing time improved preservation of poultry stocks by 8.7%.

In a study by Tang et al. [54], prebiotic potential of α-mannan (LZ-MPS, MC-MPS and G-MPS) extracted from various sources of *K. marxianus* yeasts was assessed using *in vitro* fermentation with pure fecal cultures. The results showed that α-mannan significantly balanced the intestinal microbiome composition by increasing relative abundances of *Bacteroides*, *Parabacteroides* and *Phascolarctobacterium* and decreasing pathogenic bacteria. In addition, they could be utilised as prebiotics for *Lactobacillus* and *Lactococcus* strains as well. The results showed that α-mannan significantly balanced the composition of the gut microbiome by increasing the relative abundance of Bacteroides, Parabacteroids, and Fasciolarctobacterium Sps. as well decreasing pathogenic bacteria. They could also be used as prebiotics for Lactobacillus and *Lactococcus* strains.

Roles of yeast mannan as prebiotic were clearly shown in a study by Kwak et al. [55]. They increased cell wall mannan of *S. boulardii* and *S. cerevisiae* by metabolic engineering. Adhesion capacity and sedimentation rate of the yeast - bacteria were directly linked to the quantity of mannan in the yeast cell wall. In this study, *S. boulardii* performance was more than that of *S. cerevisiae*. Bzducha Wrobel et al. [56] investigated effects of mannoproteins extracted from conventional and nonconventional yeast species on various bacteria. They detected that the type and quantity of mannan as well as the target bacterial strains were effective in inhibiting and stimulating growth of bacteria.

4.2 Effects on animal performance

Mannan can improve nutrient absorption and better animal performance by decreasing competitions between the pathogens and the host animals for nutrients [10]. In a study by Liu et al. [57], 0.2% of MOS was added to the diet of 30 7-d-old lambs for 21 d. MOS significantly increased apparent digestibility of the organic matter, crude protein, calcium and phosphorus and unsaturated fatty acid proportion and decreased diarrhea rate and saturated fatty acid proportion in lambs. Garcia Diaz et al. [58] reported that 2 g kg^{-1} of *S. cerevisiae* (10^{10} CFU g^{-1}), MOS (2 g kg^{-1}) and a combination of these additives in high grain-based diets of sheep could decrease NH_3 concentration, lipopolysaccharide translocation into the bloodstream and thickness of stratum corneum, which resulted in rumen health and further decrease incidence of liver abscesses. Investigating effects of MOS in diets of laying hens on their production performance and egg quality showed that MOS feed supplement at 1.0 kg ton^{-1} improved the production performance of laying hens and decreased the carbon footprint. Moreover, MOS supplementation did not affect egg weight, while increasing egg mass and shell thickness [59]. In a study by Ahiwe et al. [60], enzymatically hydrolyzed soluble yeast mannan at 0.15 or 0.20 g kg^{-1} diet enhanced growth performance, ileal protein digestibility and meat yield of broilers. In fish, increased growth performance, live weight, protein productivity rate, survival rate and improved fatty acid profile have been reported using diets containing MOS [61,62].

4.3 Immunomodulatory property

Studies have shown that yeast cell wall can affect innate and adaptive immune systems [63]. Higher expression rates of interleukin 8 (*IL-8) that* controls the activity of immune cells especially neutrophils as well as significant increases in the concentration of lysozyme and serum level of Immunoglobulin G (Ig G) in animals supplemented with MOS have been reported [64,65]. Another study reported that phagocytic and lysozyme activities gradually increased in fish fed increasing level of MOS diets. Fish diets containing 3 g kg^{-1} MOS showed better immune responses and disease resistances [66]. Liang et al. [67] revealed that dietary supplementation of yeast mannan enhanced antiviral immunity of fish by increasing expression of type I interferon (IFN) signaling pathway associated genes, including IRF3, IFNφ1, IFNφ2, IFNφ3 and PKZ. In contrast, it was reported that influenza virus titers increased in mannan-treated mice, compared to control. Mannan binds to host collectins, a part of the innate immune system, and decreases their ability to bind to the viruses [68,69]. Another study reported that mannan extracted from *S. cerevisiae* induced psoriasis and psoriasis arthritis inflammation in mice. Accordingly, it is understood that the immunomodulatory activity of mannan depends on the types of mannan and host animals and their immune systems [70].

4.4 Antioxidant activity

Reactive oxygen species (ROS) and other free radicals play roles in development of chronic diseases such as cancers and cardiovascular and neurodegenerative diseases, which include the majority of deaths nowadays. Therefore, removing ROS can be effective in human health [71]. In studies, antioxidant activity of the yeast mannan has been verified. Carboxyl groups in polysaccharides play roles in antioxidant properties. However, the exact mechanism of inhibiting free radicals by yeast polysaccharides is not known precisely. Antioxidant activity of polysaccharides is linked to their molecular weight (MW), glycosidic linkage and sulfation degrees [71]. In a study by Yehia et al. [12], mannan extracted from *S. cerevisiae* showed significant ability to scavenge hydroxyl radicals and superoxide anions. In addition, mannan was reported to include ntitumor activities against liver (HepG2) and breast cancer (MCF7) cell lines. In another study [72], purified mannan compounds with various MWs [172.90 kDa (YM50), 87.09 kDa (YM70) and 54.05 kDa (YM90)] were extracted from *S. cerevisiae*. *In vitro* antioxidant activity assays showed that mannan included DPPH and hydroxyl radical inhibitory activities, which depended on their MW and concentration. The highest inhibitory activity was observed with decreases in MW of mannan, which could be due to the better solubility of polysaccharides in water with lower MWs and their easier reactions with free radicals. For the three types of mannan, cytotoxicity and hemolytic activity were rarely detected in mice erythrocytes and Caco2 cells, indicating that they were biosafe polysaccharides. Similar results were achieved in a study by Wang et al. [73]. They demonstrated that scavenging abilities of Fe^{2+}, $OH^{\cdot}$ and $O_2^{\cdot}$ and protective capacities against lipid peroxidation and oxidative DNA damages were inversely linked to the molecular weight of yeast mannan.

5. Conclusion

One of the most economical method of producing bioactive compounds such as mannan includes use of yeasts. Today, yeast mannan is popularly used in animal feed industry. Although, *S. cerevisiae* has been addressed as the most well-known yeast for the mannan extraction. However, reviews of all reports have shown that other strains (*Saccharomyces* and/or non-*Saccharomyces* strains) have been also applied as high yielding strains. Various methods have been reported for manan extraction, including chemical or enzymatic methods; however, it seems that higher efficiencies of the extraction and purification can be achieved by combination of the highlighted methods based on the use of the final products and production costs. Finding a balance between the costs and high efficiencies in mannan extraction is recommended for the commercial production. The most used and cost-effective methods include acid-alkaline methods. Literature reviews have demonstrated that cultivation systems and growth conditions (e.g., carbon source, pH, aeration and temperature) include great effects on structure of the yeast cell wall, efficiency and decreased costs of mannan extraction. Furthermore, mannan production in yeast cell wall can increase by metabolic engineering. To increase bioactivities of feed supplements and decrease costs of downstream processing, extraction of mannan and β-glucan should be carried out simultaneously. Several bioactive properties, including modulation of animal gut microbiome, immune system and animal performance as well as its antioxidant activity, have been reported for mannan. These properties are claimed by the manufacturers more than other properties in commercial products. Health beneficial peoperties of mannan vary based on the species of animals and their age, diets, environmental conditions and rearing systems because these factors can affect intestinal microbiome of the animals. Thus, use of dietary supplements containing mannan in animals needs *in vivo* studies.

6. Acknowledgements

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7. Conflict of Interest

The authors report no conflicts of interest.

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مانان استخراج شده از مخمر: ساختار، استخراج و زیست فعالی

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چکیده

سابقه و هدف: مخمرها منابع ارزان و سهل الوصول ترکیبات زیست فعال ارزشمندی مانند مانان می‌باشند. مخمر، به‌عنوان فرآورده‌جانبی صنایع گوناگون، می‌تواند برای استخراج مانان مورد استفاده قرار گیرد، که تولید آن را مقرون به‌صرفه می‌کند. عوامل گوناگونی بر ساختار دیواره سلولی مخمرها تأثیر می گذارد، مانند شرایط رشد و سامانه کشت. متداولترین کاربرد مانان، استفاده به‌عنوان کمک زیست‌یار[۱] در خوراک دام است. متابولیسم مانان در دیواره سلولی روده می تواند به تولید ترکیبات پست بیوتیکی مانند اسیدهای چرب کوتاه زنجیر منجر شود. استخراج مانان به عنوان یک روش کلاسیک شناخته شده گزارش نشده است و به هزینه و کاربرد نهایی آن دارد. پرکاربردترین و مقرون به‌صرفه‌ترین روش، شیوه اسید- قلیا است. این مقاله تمام جنبه‌های ساختار، روش‌های استخراج و مطالعات اخیر در مورد کاربردها و فعالیت‌های زیستی بالقوه مانان مخمر و مانولیگوساکاریدها از جمله مدوله‌سازی[۲] میکروبیوم روده ، سیستم ایمنی و عملکرد حیوانات و همچنین فعالیت ضداکسایشی[۳] آن را بررسی کرده است.

یافته‌ها و نتیجه‌گیری: بررسی منابع علمی نشان می‌دهد که مانان، مانالیگوساکاریدها و بخش غنی از مانان و همچنین ترکیب آنها با زیست‌یارها[۴] و/یا سایر ترکیبات فعال زیستی مانند بتا-گلوکان ممکن است به مدوله سازی ترکیب میکروبیوتای روده منجر شود. مطالعات گوناگون نشان می دهد که اثربخشی مانان به نوع، سن، رژیم غذایی، شرایط محیطی و سیستم پرورش حیوان بستگی دارد. با بهینه سازی شرایط رشد و پرورش مخمر می‌توان میزان مانان را در دیواره سلولی مخمر افزایش داد که موجب افزایش راندمان تولید صنعتی می‌شودخواهد شد. اگرچه *ساکارومایسس سرویزیه* پرمصرف‌ترین مخمر در صنایع است، سایر سویه‌های ساکارومایسس (مانند *ساکارومایسس بولاردی*) و مخمرهای غیر ساکارومایسس (مانند *Pichia* و *Kluyveromyces*) نیز می‌توانند به‌عنوان سویه‌های با بازده بالا در نظر گرفته شوند.

تعارض منافع: نویسندگان اعلام می‌کنند که هیچ نوع تعارض منافعی مرتبط با انتشار این مقاله ندارند.

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واژگان کلیدی

- روش اسید-قلیا
- عملکرد حیوان
- مکمل خوراک دام
- بخش غنی از مانان (MRF)

***نویسنده مسئول**

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۱ prebiotic
۲ modulation
۳ antioxidant activity
۴ probiotics