

# Perspective of $\beta$ -Glucan as Functional Ingredient for Food Industry

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## Abstract

$\beta$ -Glucan is an important functional ingredient having many health benefits. A lot of sources for this valuable ingredient have been identified.  $\beta$ -Glucan from these sources may be extracted to fulfill the ever growing demand for nutraceutical product. The industrialists may also exploit this situation by using this functional ingredient for developing new nutraceutical products. Such products may provide health benefits beyond basic nutrition. Numerous health benefits of  $\beta$ -Glucan are documented in scientific literature that may range from simple stomach problem to complex defense shield against cancer. This review focuses on potential sources of  $\beta$ -glucan, health implications, industrial applications and immunomodulatory effect of  $\beta$ -glucan.

**Keywords:**  $\beta$ -glucan; Functional foods; Nutraceutical; Immuno-modulation; Health benefits; Cholesterol; Food industry

## Introduction

Growing interest in functional and nutraceutical product is seen in the last decade. This happened due to fast life style and concept of curing ailment through food. People all over the world have a quest for new options and concept of functional ingredient satisfy their dietary needs as these functional ingredients have a positive impact on metabolic parameters and ultimately helpful in curing chronic diseases such as diabetes, cardiovascular disease and cancer. Higher institutions all over the world are well aware of this fact and people needs. Therefore, they are developing policies to use these functional ingredients for the development of novel industrial products. For instance FDA authorized the use of health claims on the association of oat bran fiber, psyllium fiber and soy protein with coronary heart disease [1,2]. Food Industry is also in search of new nutraceutical ingredients that have documented health benefits along with better industrial application to the food product. The number of food products that can have health claims are limited at present and have a great potential for processor to occupy the market of such product that is at present in infancy.

Major food industry making use of functional ingredients is baking, beverage, meat, dairy and confectionary [3]. An annual growth rate for this industry is hitting at a figure of 7.4% that correspond to worth of more than 176 billion USD in the year 2013. Among all of this the major share is for beverage sector that is the fastest growing sector with an annual growth rate of 10.8%. This can experience more rise with more industrial innovation for the development of new functional foods that have a capacity to meet the consumer demand [4]. In Europe, functional dairy product occupied a market value of about 1345 million USD during the 2002-3 [5]. For this ever growing industry a lot of functional ingredients are available, some of these may include  $\beta$ -glucan, omega 3 fatty acids, theophyllin, antioxidants, DHA, EPA and  $\beta$ -glucan.

Chemically Beta glucan is a non starch polysaccharide with repeating units of glucose, these glucose units may branched in several ways depending upon the source from which it is extracted. The chemical structure revealed long chains of  $\beta$ -D-glucopyranose that are linked together through  $\beta$ -(1 $\rightarrow$ 3) linkage to form a long backbone whereas side chains arise through  $\beta$ -(1 $\rightarrow$ 4) linkage (Figure 1). The later may appear after 3-5 glucose units in the main backbone of  $\beta$ -(1 $\rightarrow$ 3)

linkages. The structure of  $\beta$ -glucan molecule consists of predominantly  $\beta$ -(1 $\rightarrow$ 3)-linked cellotriosyl and cellotetraosyl units [6,7] with overall glucose residues may extend more than 250,000 [8].

A lot of sources for this functional ingredient have been documented including cereals, mushrooms, yeast, algae and beans.  $\beta$ -Glucan extracted from either of the sources provide most of the cholesterol-lowering properties. However,  $\beta$ -glucan extracted from mushrooms and from baker's yeast also serves as immune system booster in dietary supplements. Chemically cereal  $\beta$ -glucan differs from yeast  $\beta$ -glucan in having  $\beta$ -(1 $\rightarrow$ 3) and (1 $\rightarrow$ 4) linkages [7]. Whereas yeast  $\beta$ -glucan having  $\beta$ -(1 $\rightarrow$ 3) and (1 $\rightarrow$ 6) linkage that may provide it better immune boosting properties [8]. Moulds  $\beta$ -glucans have similar chemical structure as the baker's yeast having long chains of about 1500 units of glucose arranged with  $\beta$ -(1 $\rightarrow$ 3) linkage and this represent about 85% of total cell wall  $\beta$ -glucans, and short chain of about 150 glucose units which is arranged in  $\beta$ -(1 $\rightarrow$ 6) fashion and this accounts for about 15% of the  $\beta$ -D-glucans [9].

A lot of health benefits of  $\beta$ -glucan reported in literature that showed its suitability for incorporating in various food products. Some of the health implications involve activity against colon cancer [10], depress hunger, better gut health [11], increased stool bulk and removal of toxic substances, anti-constipation agent [12], reduction

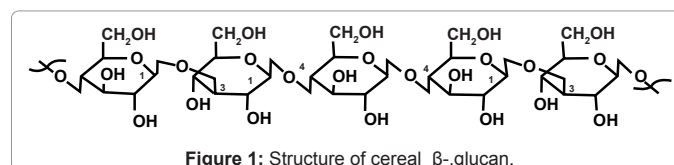


Figure 1: Structure of cereal  $\beta$ -glucan.

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in glycemic index [13], reduction in serum cholesterol [14], leveling of postprandial glucose level [15] and prevention in coronary heart disease [16].

Health implication alone is probably not sufficient to use the  $\beta$ -glucan in large food industry. It should also possess some important characteristics that can attract processors and consumers. A lot of industrial applications explored for  $\beta$ -glucan addition in the food products. Of course that is due to its promising characteristics to be used as stabilizing agent, thickening agent, gelating agent and emulsification agent. These are some important industrial applied characteristics that can turn the raw material into novel food product such as functional beverage, functional bread, ready to serve soups, functional snack foods and variety of sauces and into a big list of other food products [17,18].  $\beta$ -glucan is a major factor for controlling the quality of the product [19]. These are the some episodes from industrial applications. The industrial demand for this natural substance is fast growing. A lot of functional food products containing  $\beta$ -glucan are now being commercially introduced to the market [18,20] and their number will steadily increase in the future world market. The purpose of this article is to have an overview of  $\beta$ -glucan sources, health benefits associated with  $\beta$ -glucan, industrial applications and to understand the immunomodulating effect of  $\beta$ -glucan.

## $\beta$ -Glucan sources

A lot of sources for  $\beta$ -glucan are documented by the researchers; some are presented in Table 1 along with average  $\beta$ -glucan content in these sources. The major sources for this valuable functional ingredient include cereals and among the cereals oat and barley have higher  $\beta$ -glucan content. In cereal grains, the highest content of  $\beta$ -glucan is found in barley (2 - 11 %) and oats (2 - 7.5 %), while for wheat and rye it is a less abundant constituent and may range from 0.5-1 % and 1.4-2.6 %, respectively [21-24]. Among these sources  $\beta$ -glucan content may differ from cultivar to cultivar [25] but environmental factor sometime have little effect [26] and some time significant effect on  $\beta$ -glucan content from these sources [27]. The waxy genotypes of barley are characterized for higher levels of amylose with low starch and high  $\beta$ -glucans content [28]. The highly significant interaction between cultivars and environment suggests that it is important to plant the appropriate cultivar in a particular area in order to obtain barley seeds with reasonable  $\beta$ -glucan content. Most important factors

that can affect the recovery of  $\beta$ -glucan is the selection of source from which beta glucan can be extracted, other factors are extraction methods, extraction conditions, cultivar, location of origin and method of purification. Some relationships exist between grain  $\beta$ -glucan content and some agronomic traits; generally, high nitrogen levels increased barley grain  $\beta$ -glucan content [29]. Similarly, a negative correlation between irrigation and barley grain  $\beta$ -glucan exist [30]. For 164 cultivars, originating from China,  $\beta$ -glucan content ranged from 2.98% for Sumei 21 to 8.62% for QB25, with a mean of 4.58%. Tibet barleys, all of the hull-less type, had the highest  $\beta$ -glucan content. The seeds produced in Hangzhou had lower  $\beta$ -glucan contents than those produced locally [26]. Among other cereals, wheat also contain  $\beta$ -glucan but in very small amount that might be not feasible for commercial extraction [31]. Several researchers extracted  $\beta$ -glucan from rye [32] and rice, the later being marketed with the name of 'NutrimX' [33]. During extraction of  $\beta$ -glucan from their respective sources, the extraction rate varies and depends upon on sources, temperature, pH [25,34]. From oat the extraction rate can be achieved from 50 to 80%, barley is another good source from which 70-80%  $\beta$ -glucan is extractable. Slightly higher recoveries experienced by using yeast source, it is observed that by using *Sacchomyces cerevisiae* up to 87%  $\beta$ -glucan is extractable [35].

Among yeast *Sacchomyces cerevisiae* is the major source of  $\beta$ -glucan, other sources include *Zygosaccharomyces bailii*, *Kloeckera apiculata*, *Kluyveromyces marxianus*, *Debaryomyces hansenii*, *Kluyveromyces marxianus* and *Schizosaccharomyces pombe* [36]. The members of fungi group are also a good source of  $\beta$ -glucan. Among them researchers are focusing on edible fungi that are grown in the form of edible mushrooms. The most renowned mushroom sources include *Agaricus brasiliensis* [37], *Pleurotus tuberregium* [38], *Grifola frondosa* [39], *Lentinus edodes* [40], *Pleurotus eryngii* and *Pleurotus ostreatoroseus* [41]. A detail review of these mushrooms having  $\beta$ -glucan content is published by Lindequist [42] with reference to pharmacological importance. Other fungi sources that are not used as edible purpose can also be used for extraction of  $\beta$ -glucan that may include sources like *Termitomyces eurhizus* [43], *Penicillium chrysogenum* [16].

## Health benefits

A lot of health benefits of  $\beta$ -glucan are documented in scientific literature. The major health benefits are associated to the dietary fiber nature of this functional ingredient [52]. Dietary fiber is the part of the food that resist digestion in small intestine but micro flora in large intestine partially ferments it. On the basis of functionality, it can be classified as soluble dietary fiber (SDF) and insoluble dietary fiber (IDF). Extracted  $\beta$ -glucan from cereal and other sources have the characteristics of both SDF and IDF. The health benefits associated with  $\beta$ -glucan has been previously confirmed in animal models [53] as well as in clinical trials on human beings [54]. Therefore development of  $\beta$ -glucan rich products which could potentially reduce the incidence or slow progression of chronic diseases is of chief importance. The concept of functional foods with the emphasis on disease prevention has been predominantly implemented to develop grain based foods which are highly regarded by nutritionists. Cereals containing a wide range of macro and micro nutrients are used as a vehicle for nutrient fortification. Enrichment of foods by addition of high-fiber cereal grain containing  $\beta$ -glucan components is one way to increase fiber intake that may be helpful in reduction of bowel transit time, prevention of constipation, reduction in risk of colorectal cancer and promotion of the growth of beneficial gut micro flora [55]. Based on these health

| Source                                    | $\beta$ -glucan content(%) | Reference    |
|-------------------------------------------|----------------------------|--------------|
| Beans                                     | 2.4-3.5                    | [44]         |
| Canary seed                               | 1.1-2.3                    | [44]         |
| Corn/maize                                | 0.1-1.3                    | [44, 45]     |
| Flax                                      | 0.3-0.7                    | [44,46]      |
| Lentils                                   | 0.4-1.1                    | [44]         |
| Millet                                    | 0.5-1.0                    | [44]         |
| Peas                                      | 0.3-0.7                    | [44]         |
| Rice                                      | 0.4-0.9                    | [44]         |
| Rye                                       | 0.7-2.4                    | [44, 47]     |
| Spelt                                     | 0.6-1.2                    | [44,48]      |
| Spring wheat                              | 0.6-1.1                    | [44, 49]     |
| Winter wheat                              | 0.4-1.4                    | [48]         |
| Hulless barley                            | 3.7-9                      | [22]         |
| Barley                                    | 5-10 %                     | [50]         |
| Oat                                       | 3-7%                       | [22, 44, 51] |
| Barley mutant<br>“(HiAmi x Cheri) x Cheri | 7-12                       | [10]         |

**Table 1:**  $\beta$ -glucan content in different sources.

implications, FDA in its judgment accepted the health claims for dietary fibers including  $\beta$ -glucan from barley and oat. Similar health claims are also associated with flax fiber and soybean [2].

$\beta$ -glucan from barley and oats has good cholesterol lowering characteristics. A lot of mechanisms for cholesterol lowering are explained, but consumption or removal of precursor for cholesterol is the most accepted fact that may elucidate the effectiveness of  $\beta$ -glucan as cholesterol lowering agent [55]. Cereal  $\beta$ -glucan is highly effective in lowering both LDL, total cholesterol and serum triglycerides [56,57]. The cholesterol lowering property is dependent on molecular weight of the  $\beta$ -glucan. In a 10-week blinded controlled study the differences in high molecular weight (HMW) or low molecular weight (LMW) barley  $\beta$ -glucan (5 g dose level) on cholesterol level was explained. After completion of study period, the mean LDL-C levels fell by 15 and 13 % in the 5 g HMW and LMW group, respectively. Similar results were observed for total cholesterol [58]. In another study by Amundsen et al. [59] a 6% decrease in serum total cholesterol was recorded by consumption of same level (5 g) of  $\beta$ -glucan but from the oat source. There are evidences that circulating lipoproteins in form of LDL (bad cholesterol) or elevated levels of total cholesterol increase the risk of coronary heart diseases and lot of death are reported due to this risk factor [60]. Lowering of cholesterol through  $\beta$ -glucan consumption may provide a solution to this problem that may also reduce the risk of heart related disease [61].

An increased level of faecal bulk is associated with prevention of some major disorders. Consumption of dietary fiber including  $\beta$ -glucan may result in higher viscosity of intestinal contents and increase faecal bulk [62]. Higher viscosity of  $\beta$ -glucan is also responsible for appetite suppression, this property is ideal for persons who want to reduce weight. Viscosity property is largely dependent upon molecular weight of extracted  $\beta$ -glucan. In general, higher the molecular weight the more will be the viscosity and gelling property and this happens because of the more linkages in the chain [63]. The solubility and concentration are other factors that may affect the viscous nature of the  $\beta$ -glucan in solutions [64].

In last two decades the term glycemic index (GI) is much popularized. This concept allows the ranking of foods based on glycemic impact. This will permit an individual to self control their diets according to their needs [65] and give an idea about the food that how speedy it will be digested and absorbed as glucose [66]. At present, limited nutraceutical food products are available in the markets that can positively alter the glycemic index.  $\beta$ -glucan is a potential candidate that has the capacity to develop such nutraceutical products with low glycemic index. The development of functional foods with low glycemic index will occupy a large market for diabetic consumers [67]. Kabir et al. [68] demonstrated that consumption of low-GI breakfast containing 3 g of  $\beta$ -glucan for 4 weeks is very effective to have good glycemic control along with lowering of plasma cholesterol levels in type 2 diabetic patients [68]. However, a slightly higher amount (10 g) of  $\beta$ -glucan is required to achieve same beneficial physiological response on postprandial glucose level in obese subjects that are suffering from problem of insulin resistance [69]. Some other researchers such as Poppitt et al. [70] also demonstrated a significant reduction in glycemic index over control when  $\beta$ -glucan was incorporated in meals. This change over control was no significant when  $\beta$ -glucan was incorporated in beverage. Overall,  $\beta$ -glucan from barley and oat is responsible for reduction in postprandial glucose level through controlling endocrine response and might be used for development of new nutraceutical products [11,70].

Regular consumption of  $\beta$ -glucan from either source may result in

better gut health.  $\beta$ -glucan containing foods cause delay in emptying the gastric content and may result in slow absorption of nutrients [71]. Such foods have the capacity to alter the mixing pattern of intestinal contents thus modify the metabolism mechanism [72]. Increase in gut transit rate is a short term response that can be experienced by ingestion of  $\beta$ -glucan. This physiological response provide relief to patient of chronic constipation [71] and slow down the glucose and sterol absorption by the intestine [73,74]. At the same time  $\beta$ -glucan helps in binding excess bile acids and salts and interacts with mutagens and carcinogens in the gut for their efficient removal [71]. Positive effect of this polysaccharide was observed in patients with colorectal cancer where its consumption significantly prolongs the disease-free period [75]. The detail for anticancer activity of  $\beta$ -glucan is reported by Cheung et al., who studied the effect of  $\beta$ -glucan using the immune deficient xenograft tumor models that synergizes with anti-tumor monoclonal antibodies (mAb). The researchers also showed a good correlation between antitumor activity and the molecular size of the  $\beta$ -D-glucan irrespective of the fact whether it has got (1 $\rightarrow$ 3) (1 $\rightarrow$ 4) or (1 $\rightarrow$ 3) (1 $\rightarrow$ 6) linkages [76].

$\beta$ -Glucan showed prebiotic characteristics when incorporated in food products. There is growing market for food products having probiotics and prebiotics in their formulation. Such products are available in large food stores across the world in the form of fresh milk, yougurts, kefir products, fruit juices [77]. The prebiotic action in synergism to probiotics has major implications in maintaining gut health [71]. In fact, some prebiotics undergo fermentation by beneficial microflora in the large intestine and produce beneficial substances that are important for better gut health [77]. The major products of fermentation by gut microflora are the short chain fatty acids (SCFA) along with production of vitamins, butyrate and some other vital nutrients [71].

## Industrial applications

Food industry may take the advantage of this functional ingredient having ever growing market. Consumer demand for healthy and nutraceutical food is the major motive for this growth. To use this nutraceutical ingredient in true sense the purity of this ingredient should be at high level. This will ensure specific composition to achieve specific health benefits and remove doubts about which components are responsible for such effects. For instance the work conducted on barley or oat flour, and/or  $\beta$ -glucan enriched cereal flours, may not be directly comparable to the use of purified  $\beta$ -glucan fractions. This also leads to potential problems when incorporating these agents into food systems, in terms of predicting exact processing parameters [16]. The challenge now exists to optimize extraction procedures so as to produce consistent raw material. A lot of extraction and purification techniques were investigated by several researchers that may include hot water

| Product     | $\beta$ -glucan content (%) | References |
|-------------|-----------------------------|------------|
| Cerogen™    | 70-90                       | [72,80]    |
| Glucagel    | 75-80                       | [77,81]    |
| Ceapro      | 94                          | [82]       |
| OatVantage™ | 54                          | [55]       |
| Viscofiber  | 50                          | [50]       |
| C-trim50    | 48                          | [43]       |
| C-trim30    | 32                          | [28]       |
| C-trim20    | 21                          | [83]       |
| Natureal®   | 20                          | [84]       |
| Nature®     | 15                          | 15         |

**Table 2:** Commercial  $\beta$ -glucan products.



extraction [57], enzymatic extraction [78], acidic extraction [25], alkaline extraction [79] and solvent extraction [22]. Each technique has its own merits and limitations. The commercial products available in the market vary in the method of  $\beta$ -glucan isolation, concentration, molecular weight, water holding capacity and viscosity. Some of the important commercial products of  $\beta$ -glucan along with  $\beta$ -glucan content are presented in Table 2.

Several researchers incorporated  $\beta$ -glucan in cereal based, meat based and dairy based products [81,85,86] but still more investigations are required to better understand the role of this ingredient in other products. For instance, molecular weight profile of  $\beta$ -glucan has multidimensional effect on product development. It may affect the viscous nature, gel formation, rheological properties and other industrial important properties [87]. On the other hand it may also alter specific health benefits that are intended to achieve for a specific purpose. Further study also needed on the potential effects of incorporating  $\beta$ -glucan into both dairy and cereal-based food systems in reference to rheological characteristics and molecular profiles of  $\beta$ -glucan [16]. Such research would broaden our understanding of how  $\beta$ -glucan can affect the nutritional characteristics of foods by altering their structure, texture and viscosity. Relevant literature on  $\beta$ -glucan incorporation into finished products indicate the influence of various factors (molecular weight, solubility, concentration) in such products during processing operations. To ensure a better product during processing, the processor must pay attention to processing methods, functional properties of  $\beta$ -glucan, enzymatic and mechanical cleavage of  $\beta$ -glucan molecule. A close focus on these factors will allow the processor to produce a product with desirable features that have the capacity to meet consumer demand for nutraceutical food [88].

White bread when prepared with traditional recipe will be always lacking dietary fiber. But there always exist a demand for high fiber white bread. Such type of bread is possible with inclusion of 'Glucagel' that is the trade name for beta glucan preparation extracted from barley. *In vitro* analysis of these bread samples revealed a significant decrease in reducing sugar release over a 300 min digestion in breads supplemented with 5% Glucagel sample. However, incorporation of Glucagel increase starch availability for digestion. This has implications in the reduction of hyperglycemia and hyperinsulinemia, with reference to the control of diabetes [89]. Similar to 'Glucagel' another commercial soluble fiber brand 'RiceTrim' is available in Asian markets. This brand is made up of rice bran and barley flour and is a good source of  $\beta$ -glucan. It may also utilize as fat replacer for the manufacturing of coconut cream with good rheological properties. Other usage includes Cookies, pumpkin pudding, layer cake, dip for pot crust, taro custard and sauté and chicken curry [33]. Another reason for incorporating  $\beta$ -glucan in cereal products is the better viscoelastic properties in the dough that facilitate during mixing and proofing operations, as a result of this processor can achieve optimum bread crumb softness [90]. This incorporation in cereal products also adds value to the organoleptic properties in the final product [25]. In an attempt to produce acceptable pasta products by using  $\beta$ -glucan containing barley flour Knuckles et al. [91] was able to produce pasta product. This product was a good source of dietary fiber containing 5.8 g dietary fiber compared to less than 2 g in the same product conventionally made by all wheat flour. This product still has good acceptability as determined by organoleptic tests [91].

Dairy based products have a great potential to utilize  $\beta$ -glucan to develop new nutraceutical products. Bekers et al. [92] developed a new functional bioactive dairy based food containing oat  $\beta$ -glucan.

This product address the idea of symbiotic combination of probiotics and prebiotics and dietary fiber is released during fermentation process [92]. Possibility of incorporation of oat based  $\beta$ -glucan for the development of functional yogurt also showed promising result. In such product,  $\beta$ -glucan addition improved the body and texture of unsweetened yogurts. Apparent viscosity was also increased but in combination with sweeteners [93]. Addition of  $\beta$ -glucan also stimulates the fermentative bacteria in the dairy products and produce functional bioactive substance [94].

Molecular weight is much more important to understand industrial application of  $\beta$ -glucan.  $\beta$ -glucans preparation with molecular weight up to 3 million Da [95] is considered larger molecules and have tendency to introduce high viscosity in the products. This higher viscosity is attributed to very strong intramolecular associations within the same molecule or with intermolecular association with other constituents of the product. It is possible to make pseudoplastic solution by the use of  $\beta$ -glucan; these solutions have greater importance in food industry. Such type of solution follows the power law and conditional for higher concentrations of  $\beta$ -glucan the Herschel-Bulkley model. The flow behaviour index varied from 0.97 and 0.31, indicating mild to highly pseudoplastic solutions of  $\beta$ -glucan, respectively, where the pseudoplasticity increased with the concentration [80]. The application of low molecular weight  $\beta$ -glucans (9000 Da) seems to be appropriate for manufacturing of soft gels as these type of  $\beta$ -glucan molecules easily rearrange themselves due to less linkages [96]. The viscosity in low molecular weight  $\beta$ -glucan systems is dependent on molecular weight, concentration and solubility [73]. Depending on molecular weight it is possible to prepare thixotropic suspensions, viscoelastic food systems and pseudoplastic solutions [33,16]. This phenomenon is achieved due to exposure to physical forces and chemical or enzymatic hydrolysis that tends to alter the molecular size of  $\beta$ -glucan in range of 0.4–2 million Da that is suitable in most typical food preparations [97].

Multi functional role of  $\beta$ -glucan in different food systems allow the processors to incorporate this valuable ingredient in range of products. That may include low fat ice-cream [83], low fat cheese [19], soft brined cheeses [63] and low fat sausages [98]. There are also some indications that these molecules might have useful functional properties in food structures, for example in promoting whipping and emulsification [99,18]. Other applications of  $\beta$ -glucan that are reported in past two decade are soups, sauces, beverages [100,101]. When incorporated in such products that have the ability to replace conventional used thickeners [102]. Processor may also consider the addition of  $\beta$ -glucan to achieve characteristics like improved viscosity, water-holding capacity, oil-binding capacity, emulsion stabilization and improvement in organoleptic characteristics of these products [103-105].

### Immunomodulation effect of $\beta$ -glucan

Beta glucan extracted from yeast and fungi have 1→3 backbone with side branches linked through 1→6 linkages. This chemical nature is very effective for immunomodulating affect of  $\beta$ -glucan. The mechanisms involving immunomodulation effect of  $\beta$ -glucan are depicted in Figure 1. Immunomodulation along with response modification have application in cancer patients where these serve as immunity booster in such patients and also reduce the side effects of chemotherapy [106]. Beta glucan in such patients improve the capacity of specific immune cells through release of cytokines, these cytokines transmit specific signals to other immune cells. Thus a cascade of information transduction system initiate that stimulate the entire immune system against unwanted cell growth. This has application in

treatment of malignant tumor and cancerous growth. Beta glucan can produce both innate and acquired immune response through binding with macrophage, neutrophils and natural killer cells. An interaction of  $\beta$ -glucan with natural killer cell in T- lymphocyte system results in cytokine production that may cause lysis of infected cells and also activate innate immune response through macrophage [107].

Molecular and cellular level work for yeast  $\beta$ -glucan having 1 $\rightarrow$ 3 and 1 $\rightarrow$ 6 linkages indicate the possibility of  $\beta$ -glucan to act as antitumor agent and also bear good immunostimulants agent against infectious disease. Some researchers claimed these affects can be achievable through granulocytes stimulation, macrophages, monocytes and NK-cells [108]. These processes are further triggered through T cell response; as a result of this macrophage more actively secrete IFN- $\gamma$ , IL-6, IL-8 and IL-12. Such tumorocidal roles are already confirmed by Bohn and BeMiller [109] while working on mice models. To achieve this immunomodulatory effect, the mode of administration of  $\beta$ -glucan is very important that may affect the solubility of  $\beta$ -glucan. intravenously or intraperitoneally is the most used routes of administration. Insoluble  $\beta$ -glucan will be problematic if administered through parenteral routes and may cause microembolization, granuloma formation, pain and severe inflammation [110]. To overcome these problems, an oral administration of the water-soluble glucan preparations is suggested. To overcome the problem of weak solubility, use of modified  $\beta$ -glucan is practical. In this case several chemically modified derivatives such as carboxy-methylated  $\beta$ -glucan, sulfated  $\beta$ -glucan and phosphate  $\beta$ -glucan is more appropriate [111-113]. Some protective effect of sulfoethyl glucan (sulphur containing modified derivative of  $\beta$ -glucan) against mutagenicity induced by potassium bichromate in mice was also reported [114]. This derivative is also exhibited anti-infective activity against *Klebsiella pneumoniae* after intravenous or subcutaneous prophylactic application to mice [115].

Ingested or administered  $\beta$ -glucan stimulate human monocytes, as a result of this stimulation cascade of reactions start that ultimately give birth to tumor necrosis factor- $\alpha$  (TNF- $\alpha$ ) and interleukin-1 $\beta$  by a mechanism dependent on trypsin-sensitive  $\beta$ -glucan receptors [116]. This mechanism initially involves binding of  $\beta$ -glucan on specific protein. Two substances *in viz.* vitronectin and fibronectin are identified as major glucan binding proteins. A strong complex of  $\beta$ -glucan with these proteins ensures the release of macrophage cytokines [117,118].  $\beta$ -Glucan is important in control of several fungus diseases. It is well known that particulate consumption of  $\beta$ -glucan have a priming effect for IL-12 production that may be exploited for the control of Paracoccidioidomycosis that is an important fungal disease large spread in parts of Latin America [119]. Along with this immune boosting mechanism, soluble  $\beta$ -1 $\rightarrow$ 3-glucan in combination with other lipopolysaccharides enhances the IL-8 and IL-10 and monocyte activity within the effected tissues. This glucan complexes also strongly primed for TNF- $\alpha$  and IL-6 induction by LPS [120]. In another instance, Větvíčka et al. [121] showed that soluble CR3- specific polysaccharides such as  $\beta$ -glucan induce a primed state of CR3 that can trigger the killing of iC3b target cells that were otherwise resistant to cytotoxicity [121]. Overall,  $\beta$ -glucan itself is non toxic against tumors but acting as response modifier and have immunostimulative action against tumor cells [122].

## Conclusions and Implications

$\beta$ -Glucan is a valuable functional ingredient that possesses numerous health benefits. Its role in controlling hyperglycemia and hyperlipidemia is extraordinary. Detailed mechanisms on these effects

are well enumerated in previous literature. Recent research focus on  $\beta$ -glucan immunomodulatory effects with anticarcinogenic activity makes this substance valuable for future food and pharmaceutical industry. Industry can also take the benefits of its use as stabilizer, viscosity enhancer, fat replacer, gelling agent and plasticizing agent. Despite the numerous applications, challenges still exist for its extraction and purification. New product development on the basis of molecular weight characterization of  $\beta$ -glucan is another avenue for future investigations. Overall  $\beta$ -glucan possesses multidimensional characteristics to be added as functional ingredient in foods.

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