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CURRENT DEVELOPMENTS ON β-GLUCANS AS FUNCTIONAL COMPONENTS OF FOOD: A REVIEW

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Abstract
Functional components of food are the standardized and characterized fractions or extracts containing bioactive ingredients or non-conventional nutrients of varying purity. β-glucans are part of these functional components. They are naturally occurring constituents of the cell walls of cereals and certain bacteria and fungi where they exist as soluble dietary fibre. Chemically, they are non-starchy polysaccharides. Structurally, they are heterogeneous group of glucose polymers, consisting of a backbone of β(1,3)-linked D-glucopyranosyl units to which either β(1,6) or β(1,4) side chains of varying distributions and lengths are linked. Cereal and bacterial β-glucans are primarily linear with large regions of β(1,4) linkages separating shorter stretches of β(1,3) structures. Fungi β-glucans have short β(1,6)-linked branches coming off the β(1,3) backbone while those of yeast have β(1,6) branches that are further elaborated with additional β(1,3) regions. These structural differences do have large implications and impact on their activities. β-glucans have plenty of health benefits including the control of blood cholesterol, low glycaemic response, prebiotic, and immunomodulatory effects. In addition, the multidimensional and functional characteristics of β-glucans are of great commercial and nutritional importance with great potentials of application in the food and pharmaceutical industries as stabilizers, viscosity enhancers, fat substitutes, gelling and plasticizing agents. Based on supporting scientific evidences, various health claims in respect of β-glucans have been verified and approved in the U.S., U.K., Sweden ant the EU. This paper, therefore, reviews current developments on β-glucans as functional components of food with regards to their physiological benefits, health claims and applications.

Keywords: β-glucans, dietary fibre, functional components, health benefits, nutrients.

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1. INTRODUCTION

β-glucans are commonly referred to as dietary fibre (DF). However, what constitutes dietary fibre has been under debate for a long time now. The AACC (2001) defined dietary fibre as the edible part of plants or analogous carbohydrates which include polysaccharides, oligo-saccharides, lignin, and associated plant substances such as arabinoxylans and cellulose that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine and promotes beneficial physiological effects including laxation, and/or attenuation of blood cholesterol, and/or blood glucose. A dietary fibre is mostly derived from plants and is composed of complex, non-starchy carbohydrates and lignin that are not digestible within the small intestine – since mammals do not produce enzymes capable of their hydrolyses into constituent monomers (Turner and Lupton, 2011). However, dietary fibre is considered a non-nutrient and contributes no calories to our diet as it reaches the colon intact. In the colon, dietary fibres are fermented by the beneficial bacteria, and metabolized into volatile acids with the release of energy (Pravst, 2012; Havrlentova et al, 2011).

Based on its water solubility, dietary fibre can be divided into two categories: water-soluble and non-water solube. Water-soluble fibre predominantly consists of non-starchy polysaccharides, mainly β-glucans, gums, pectin, mucilage and arabinoxylans. It produces a viscous solution. Soluble fibre inhibits passage of the chyme through the intestines; hampers stomach discharge; reduces the absorption of glucose and sterols in the intestines; and decreases serum cholesterol; blood glucose; and the content of insulin in the human body. The water-insoluble fibre contains lignin, cellulose, and hemicellulose. It is not fermented in the large intestine (AACC

2001; Andlauer and Furst 2002; Charalampopoulos et al, 2002).
It is however necessary to also mention some negative aspects of dietary fibre in human nutrition. The potential negative effects of dietary fibre include reduced absorption of vitamins, minerals, proteins, and calories (*Marlett et al, 2002*). Excessive amounts of dietary fibre causes diarrhoea (*Saibil 1989*) while its fermentation by anaerobic bacteria in the large intestine produces gas, including hydrogen, methane, and carbon dioxide, which may be responsible for the complaints of distention and flatulence (*Marlett et al. 2002*).

2. SOURCES, OCCURRENCE AND STRUCTURE

β-glucans are naturally occurring homopolysaccharides. These glucose polymers occur in a variety of organic sources such as plants (cereals and seaweed) and are the most abundant sources of polysaccharides found inside the cell wall of bacteria (*Pneumocystis carinii, Cryptococcus neoformans, Histoplasma capsulatum*) and fungi such as mushrooms and *Saccharomyces cerevisiae* (Akramiene et al, 2007; Chan et al, 2009; Havrlentova et al, 2011). Among yeasts, *Sacchromyces cerevisiae* is the major source of β-glucan, other sources include *Zygosaccharomyces bailii, Kloeckera apiculata, Kluyveromyces marxianus, Debaryomyces hansenii, Kluyveromyces marxianus* and *Schizosaccharomyces pombe* (*Nguyen et al, 1998*). Other members of the fungi group are also good sources of β-glucans. Among them are the edible fungi that are grown in the form of edible mushrooms. The most renowned mushroom sources include *Agaricus brasiliensis* (Mizuno et al, 2003), *Pleurotus tuberregium* (Zhang et al, 2004), *Grifola frondosa* (Kodama et al, 2003), *Lentinus edodes* (Chihara, 1993), *Pleurotus eryngii and Pleurotus ostreatoroseus* (Carbonero et al, 2006). The most frequently studied β-glucans obtained from mushrooms include lentinan from *Lentinus edodes*, grifolan (also called GRN and grifolan LE) from *Grifola frondosa*, schizophyllan (also known as SPG, sonifilan, sizofiran, and sizofilan) from *Schizophyllum commune,* SSG from *Sclerotinia sclerotiorum*, PSK (also known as crestin), and PSP (polysaccharide peptide) from *Coriolus versicolor* and β-glucan isolated from *Pleurotus ostreatus* called pleuran (Chang 1996). Other non-edible fungi sources that can be used for extraction of β-glucans include *Termitomyces eurhizus* (Chakraborty et al, 2006), *Penicillium chrysongenum* (Wang et al, 2002).
β-glucans are concentrated in the internal aleurone and subaleurone layers of the endosperm cell wall of cereals (Charalampopoulos et al 2002; Demirbas 2005; Holtekjolen et al, 2006), notably barley and oat grains (Havrlentova and Kraic 2006). Microbial glucans can be found generally inside or on the surface of microbial cells or are excreted by microbial cells into the neighbouring environment extracellularly. Surface glucans are carriers of immunochemical specificity. Some of them such as β(1→3)-D-glucans can stimulate the immune mechanisms of the host and have also antitumour and antimicrobial effects (Ooi and Liu 2000; Vetvicka et al, 2002; Vetvicka and Yvin 2004).
Structurally, β-glucans are heterogeneous group of glucose polymers, consisting of a backbone of β(1,3)-linked D-glucopyranosyl units to which either β(1,6) or β(1,4) side chains of varying distribution and length are linked. Cereal and bacterial β-glucans are primarily linear with large regions of β(1,4) linkages separating shorter stretches of β(1,3) structures (Figure 1). Fungi β-glucans (e.g. mushroom) have short β(1,6)-linked branches coming off the β(1,3) backbone while those of yeast have β(1,6) branches that are further elaborated with additional β(1,3) regions (Figure 2).
These structural differences do have large implications and impact on their activities, e.g. water solubility. Also, differences in the length of the polysaccharide chain, extent of branching, and the length of those branches can result in differences in hot water extracts

(HWE), level of viscosity and differences in molecular weights of β- glucans (Akramiene et al, 2007; Chan et al, 2009; Havrlentova et al, 2011, Pravst, 2012).

3. FUNCTIONAL PROPERTIES OF β-GLUCANS

The structural features of β-glucans greatly influence their molecular shape and the behaviour of the polysaccharide in solution, including viscosity. The primary source of β-glucans and the production processes therefore have a great impact on their functionality (Pravst, 2012). Some properties of β-glucans which bear on their functionality as bioactive components of food are as follows.

A. Physical Properties

The mixed linkage structure of β-glucans and length of the polysaccharide chain (degree of polymerization: DP) are responsible for their specific physical properties and characteristics such as viscosity, solubility, molecular weight, water binding capacity (WBC), foamability (foam capacity and stability).

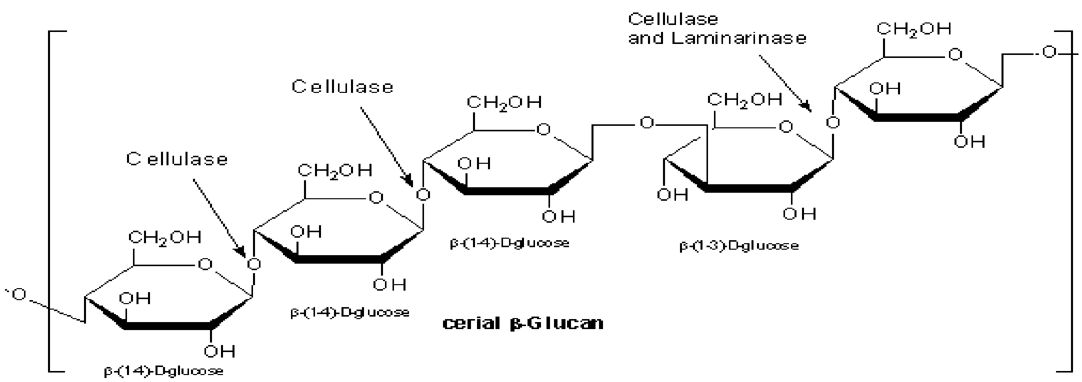

Fig. 1: β-glucan from cereals (β-1,3 linear chain with β-1,4 branch link bonds). Source: Sigma-Aldrich (2013).

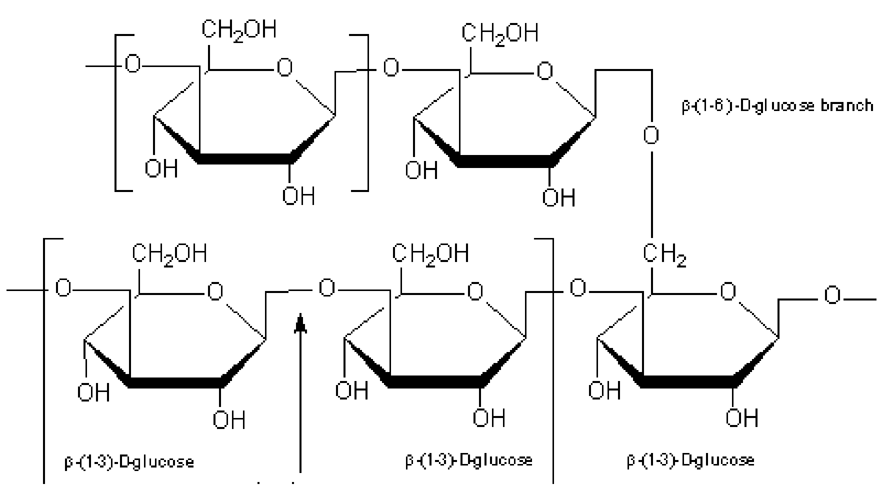

Fig. 2: β-glucan from fungi (β-1,3 linear chain with β-1,6 branch link bonds). Source: Sigma-Aldrich (2013).

These linkages prevent compact folding of β-glucan chains, making them soluble in water (Ahmad et al, 2009; Duss & Nyberg, 2004). β-glucans are asymmetric molecules which appear like an extended coil (worm-like chains) in aqueous solution (Gomez et al, 1997; Buliga et al, 1986). The water binding capacity (WBC) of β-glucan measures the amount of water retained by the fibre after being subjected to stress such as centrifugation. These hydration properties of β-glucan are important in many food applications and have an impact on the shelf life of food products. The functional properties of foam capacity and stability are equally important when β-glucans are used as a functional ingredient and stabiliser in batters. Often a high foaming capacity and stability is desirable in cakes and batters (Ahmad et al, 2009).

Values of some physical properties of β-glucans documented in literature vary as follows: molecular weight, 2.68×10^4 to 3.0×10^6 g/mol; water binding capacity, 2.91to 3.79 g/g (dry weight basis); viscosity of 1.0 % w/v solution, 34.30 to 52.80cP; foam capacity, 122 to 160 % and foam stability, 65.20 to 68.20 %. These variations depend probably on differences in sources, processing and methods of determination (Beer et al, 1997; Aman et al, 2004; Anttila et al, 2004; Ahmad et al, 2009). Increased viscosity is a fundamental characteristic of β-glucan solutions and has an important impact on their physiological behaviour and functions such as cholesterol-lowering effects and glycaemic response in the gastrointestinal tract (Wood et al, 1994; Beer et al, 1997; Anttila et al, 2002; Anttila et al, 2004; Duss & Nyberg, 2004).

To maintain their functional attributes, it is important that the processing of β-glucans does not destroy their structure. These large macromolecules are mechanically sensitive and can be broken at high shear rates (Duss & Nyberg, 2004).

B. Chemistry of β-Glucans

Chemically, β-glucans are polymers of glucose molecules linked with β bonds with linear and branched structures, thus they are non-starchy in nature. They differ from cellulose by having branched chains in addition to the straight linear chain. While β-glucans are soluble fibre as a result of their linear and branched linkages which allow water to penetrate and solubilize them, cellulose is non-soluble because its long straight chain is closely packed and water molecules cannot penetrate it (Wood, 1993b; Duss & Nyberg, 2004).

In β-glucans, the β(1,3) linked glucose units form the backbone of the structure with either β(1,4) or β(1,6) linked glucose units forming the branched linkages depending on whether the source of the glucan is either cereal and bacterial or fungal. Because the distribution of the linkages is not random but occurs at irregular intervals, the overall shape of the polysaccharide is irregular, which reduces its tendency to pack into stable, regular molecular aggregates and enables the formation of stable viscous solutions. The intestinal bonds cannot digest the β bonds of β-glucans (Wood, 1993a; Pravst, 2012).

4. PHYSIOLOGICAL BENEFITS

Plenty of health benefits of β-glucan are extensively documented in literature (Johansson, 2006; Otles and Cagindi, 2006; Duss & Nyberg, 2004; Wolever et al, 2010; Havrlentova et al, 2011; Ahmad et al, 2012b). The major health benefits of β-glucans are associated with the water binding capacity of soluble dietary fibre. This characteristic mainly relates to its ability to improve viscosity of meals in the small intestine and thus delay the absorption of nutrients (Ahmad et al, 2012a, Pravst, 2012). Dietary fibre is the part of food that resists digestion in small intestine but undergoes partial fermentation by the micro flora in the large intestine. On the basis of functionality, extracted β-glucans from cereals and other sources have the characteristics of both soluble dietary fibre (SDF) and insoluble dietary fibre (IDF). The health benefits associated with β-glucans have previously been confirmed in animal models (Anderson, 1995; Chan et al, 2009) as well as in clinical trials on humans (Wolever et al, 2010).

A. Cholesterol-lowering effect

Substantial evidence in the last thirty years has shown that β-glucan has good blood-cholesterol-level lowering characteristics and control of lipoprotein metabolism (Truswell, 2002; Lia-Amundsen, 2003). Cereal β-glucan is highly effective in lowering LDL, total cholesterol and serum triglycerides (*Pomeroy et al, 2001; Ahmad et al, 2010*). The cholesterol lowering property is dependent on the molecular weight of β-glucan (Queenan et al, 2007; Kapur et al, 2008; Cui and Wang, 2009). They are believed to exercise this effect mainly by increasing the viscosity of the intestinal contents and faecal bulk and at the same time help in binding excess bile acids and salts and slow down sterol absorption in the intestine (Kahlon and Chow, 1999; Monro, 2002; Malkki 2004; Warrand, 2006; Butt et al, 2008). Different theories concerning the mechanisms of cholesterol-lowering effects of β-glucans have been postulated. One theory proposes that the viscous β-glucans encapsulate bile acids, resulting in their loss in faeces; the body looses them and synthesizes new ones in the liver. The building block for bile acids is cholesterol, which the liver extracts from the blood thereby decreasing body cholesterol levels (Marlett et al, 1994). Another hypothesis postulates that the fermentation of soluble dietary fibre by probiotic bacteria in the colon produces propionate. The propionate is then absorbed by the colon cells and sent to the liver where it is thought to have an effect on cholesterol synthesis. A third theory further proposes that β-glucan interfere with the absorption of lipids in the gastrointestinal tract, probably by reducing or lowering the emulsification and lipid hydrolysis process (Lia, 1997).

B. Low glycaemic response or index

In the intestine, β-glucan absorbs fluids and increases the viscosity of intestinal bulk during digestion, resulting in slow digestion and extended transit period through the gut. With such delay in digestion, blood sugar increases slowly causing a low insulin response. This is known as low glycaemic response or index, LGI (Brand-Miller et al, 2001; Jenkins et al, 2002). However, the mechanism of the effect is not fully understood. One hypothesis is that in the intestine food is incorporated in the viscous β-glucan rendering it more difficult for the degrading actions of the intestinal enzymes. Another hypothesis proposes that β-glucan form a protective layer along the intestinal wall that acts as a viscous barrier, slowing nutrient absorption from the intestine (Battilana et al, 2001). Rapid digestion of carbohydrates results to rapid absorption of sugars from the intestine into the blood stream and consequent rapid secretion of insulin from the pancreas causing a high glycaemic response or index, HGI (Duss and Nyberg, 2004). Epidemiological data suggest that low GI diets may help prevent type II diabetes and obesity, cardiovascular diseases, coronary heart diseases, metabolic syndrome and reduce insulin resistance (Tappy et al, 1996; FAO, 1998; Liu et al, 1998; McKeown et al, 2004; Wood et al, 2000). Such foods have the capacity to alter the mixing pattern of intestinal contents thus modifying the metabolic mechanism (Schneeman, 2002). This physiological response provides relief to patients of chronic constipation (Warrand, 2006).

C. Prebiotic effect

β-glucans are indigestible in the small intestine but exhibit prebiotic characteristics through microfloral fermentation in the colon (Ahmad et al, 2012b; Malkki and Virtanen, 2001). Their activities as prebiotics in synergism with probiotics have major implications for better gut health (Warrand, 2006; Duss & Nyberg, 2004). Oat β-glucans have been shown to have a potential in the prevention of colonic diseases, ulcerative colitis, and colon cancer (Kim et al, 2006; Nilsson et al, 2008). The major products of prebiotic fermentation by gut microflora are short chain fatty acids (SCFA), e.g. butyrate, vitamins and other nutrients for mucosal cells (Tomasik and Tomasik, 2003; Duss & Nyberg, 2004).

D. Weight management

β-glucans form a thick viscous fluid in the stomach and small intestine that can induce the feeling of satiety when consumed about 20 – 30 minutes before eating a meal and by so doing helps suppress appetite. By reducing the desire for food intake and extending the period of digestion, nutrients are absorbed and utilized by the body over a longer period of time (Duss & Nybert, 2004; Ahmad et al, 2012b). The effect can help in weight management and control when combined with a healthy nutrition based on healthy diet and adequate exercise (Marlett, 1993; Ludwig, 2000).

E. Effects on the immune system

The chemical nature of microbial β-glucans (from fungi especially, yeast) is very effective in immunomodulating activities (Ahmad et al, 2012b). They have been reported to act as immune system activators and cell response modifiers. Their binding to specific receptors can elicit a serial cellular response through the modulation of activities of various factors including cytokines, chemokines, transcriptional factors, and growth factors (Akramiene et al, 2007). The process mechanisms of the effects of β-glucans on the immune system are complex and beyond the scope of this paper. Detailed mechanisms of these effects are well enumerated and documented in literature (Akramiene et al, 2007; Chan et al, 2009; Ahmad et al, 2012b) However, simplified illustrations of these mechanisms are demonstrated below.

a. Increase in resistance to infections

Based on data from *in vitro* and *in vivo* animal studies, β-glucans enter the proximal small intestine rapidly and are captured by the macrophages after oral administration. The β-glucans are then internalized and fragmented into smaller sized β-glucans and are carried to the marrow and endothelial reticular system. The small β-glucans fragments are then released by the macrophages and taken up by the circulating granulocytes, monocytes and dendritic cells (Figure 3). The immune response will then be elicited (Chan et al, 2009; Brown & Gordon, 2001).

b. Immune modulating activity

β-glucans can bind and act on a diversity of immune related receptors, especially, Dectin-1 and complement receptor cells (CR3), to trigger a wide spectrum of immune responses. The targeted immune cells of β-glucans include macrophages, neutrophils, monocytes, natural killer (NK) cells and dendritic cells (Figure 4). Thus a cascade of information transduction system is initiated that stimulates the entire immune system against unwanted cell growth. The immunomodulatory functions induced by β-glucans involve both innate and adaptive immune responses (Brown, 2006; Akramiene et al, 2007; Novak and Vetvicka, 2008; Chan et al, 2009).

c. Anti-carcinogenic effect

β-glucans are reported to have no direct cytotoxic effects. They do not trigger any apoptotic pathways; hence do not exercise any direct anti-carcinogenic effects on common cancer cells including carcinoma, sarcoma, and blastoma (Chan et al, 2009). However, immunomodulatory effect of β-glucans along with response modification is beneficial in the chemo- and radio-therapy treatments of cancerous growths because it serves as immunity booster in such patients (Akramiene et al, 2007; Novak and Vetvicka, 2008). β-glucans in such patients improve the capacity of specific immune cells through the release of cytokines. These cytokines transmit specific signals to other immune cells (Figure 4: Brown, 2006). In addition, immunomodulation effect of β-glucans can also be applied in the treatment of malignant tumor cells (Figure 3).
However, β -glucans themselves are non-toxic against tumors but act as a response modifier and have immunostimulative action against tumor cells (Takeda and Okumura, 2004).To achieve these applications of the immunomodulating activity of β-glucans, the mode of administration of β-glucan is very important because this may affect its solubility. Intravenous administration is the most used

mode of administration. Insoluble β-glucan will be problematic if administered through alternative routes and may cause microimmobilization, granuloma formation, pain and severe inflammation (Maeda et al, 1988). To overcome these problems, an oral administration of the water-soluble glucan preparations is suggested as alternative (Ahmad et al, 2012b).

5. HEALTH CLAIMS

Several claims have been made in respect of the beneficial and positive effects of β-glucans on health and well-being. Some of these claims have been evaluated and authorized in some countries.

A. Approved health claims in the United States of America (U.S.A).

In 1997, the U.S. Food and Drug Administration (FDA) reviewed 37 clinical studies concerning the claimed effect of oat β-glucans on blood cholesterol, especially the dose-response of the effect. Based on the findings, the FDA approved the first food-specific claim for oat β-glucan by authorizing the use of a health claim thus: *"Soluble fibre from foods such as oat bran, as part of a diet low in saturated fat and cholesterol, may reduce the risk of coronary diseases"*. The claim was based on a daily intake of 3 g of oat β-glucans, and the food product must contain at least 0.75 g per servings (*FDA, 1997*).

B. Approved health claims in the United Kingdom (U.K).

In the U.K., the Joint Health Claims Initiative (JHCI) Expert Committee and Council confirmed a health claim: *"Whole-oats, oat bran, rolled oats and whole-oat flour, as part of a diet low in saturated fat and a healthy lifestyle, can reduce cholesterol"*. Products carrying the claim should contain at least 0.75 g of soluble fibre (β-glucans per serving), which is one-quarter of the suggested daily intake of 3 g (JHCI, 2004).

C. Approved health claims in Sweden.

In Sweden, a product-specific claim*: "That the product balances or evens out blood glucose levels after a meal"* has been approved for a yoghurt and musli containing β-glucans. Another generic claim in two steps about the blood cholesterol lowering effect of oat fibres has also been approved to read: *"Soluble fibres may as part of a healthy diet, contribute to healthy cholesterol levels. This product is rich in soluble oat fibres"* (Duss & Nyberg, 2004).

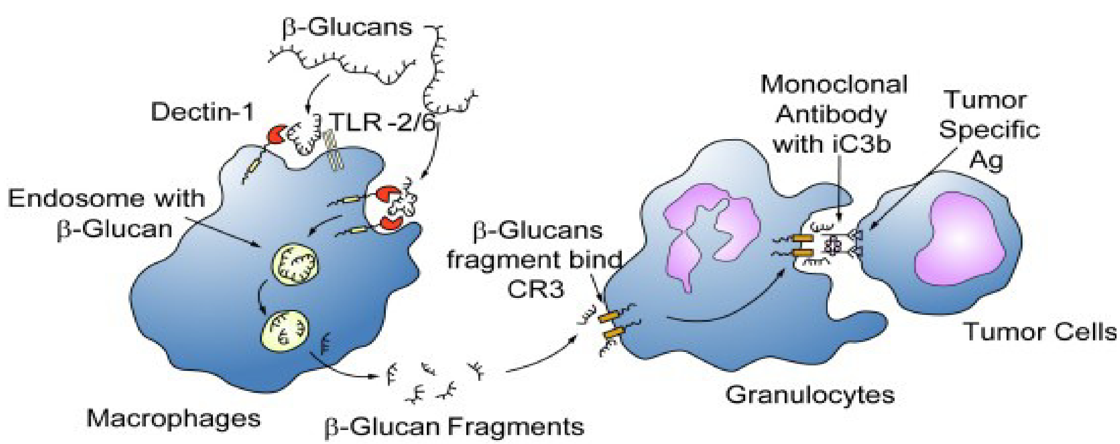

Fig. 3: The uptake and subsequent actions of β-glucan on immune cells.

Legend Description: β-glucans are captured by macrophages via the Dectin-1 receptor with or without toll-like receptors 2 & 6 (TLR-2 & 6). The large β-glucan molecules are then internalized and fragmented into smaller sizes within the macrophages. They are carried to the marrow and endothelial reticular system and subsequently released. These small β-glucan fragments are eventually taken up by the circulating granulocytes, monocytes or macrophages via the complementary receptor 3 (CR-3). This turns on the immune response; one of the actions is the phagocytosis of the monoclonal antibody tagged *tumor cells.*

Source: Chan et al (2009).

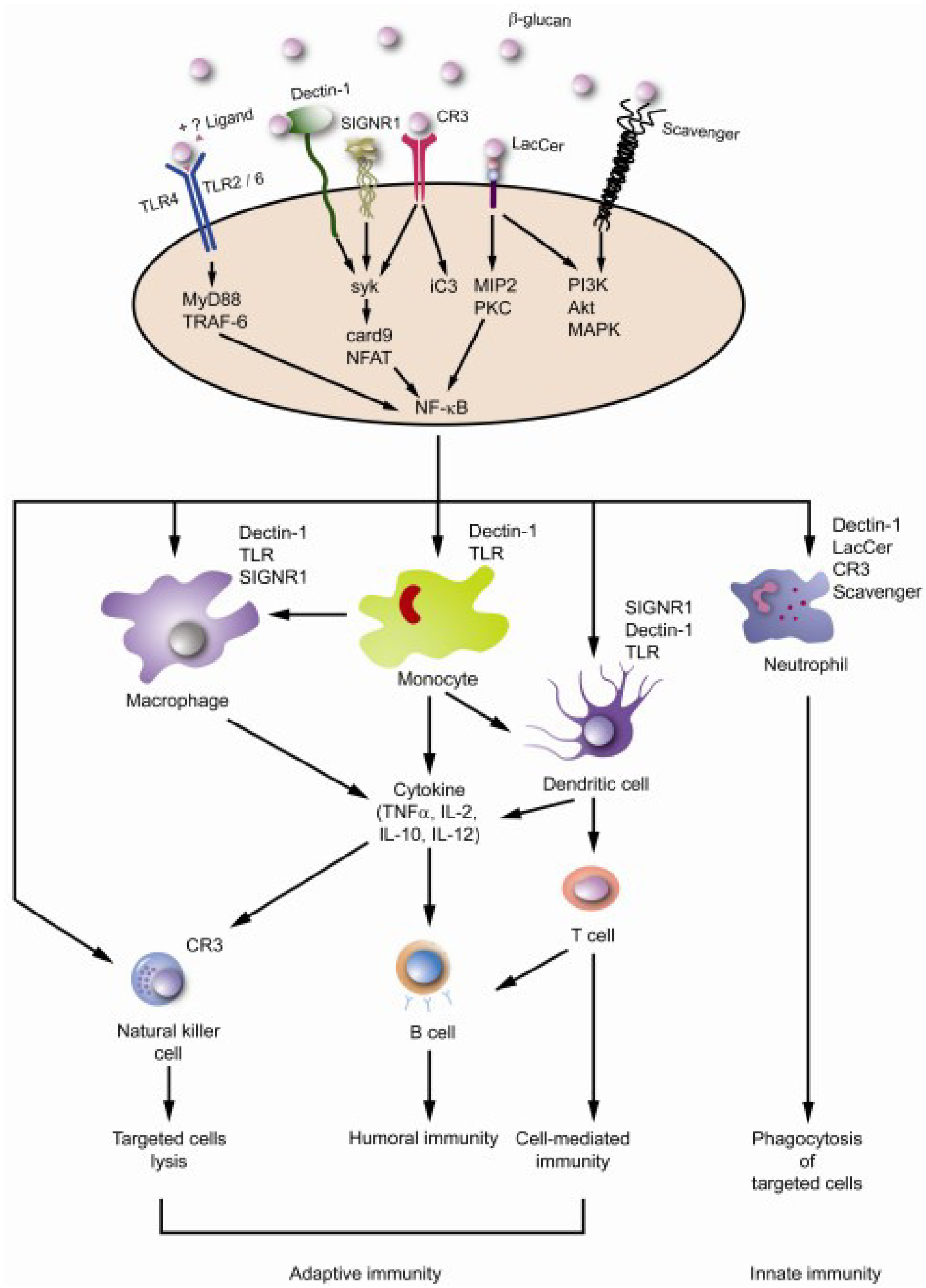

Fig. 4: Immune activation induced by β-glucans.

Legend Description: β-glucans act on a variety of membrane receptors found on the immune cells. They may act singly or in combination with other ligands. Various signaling pathways are activated and their respective simplified downstream signaling molecules are shown. The reactor cells include monocytes, macrophages, dendritic cells, natural killer cells and neutrophils. Their corresponding surface receptors are listed. The immunomodulatory functions induced by β-glucans involve both innate and adaptive immune responses. β-glucans also trigger a cascade of the release of cytokines, such as tumor necrosis factor (TNF)-α and various types of interleukins (ILs).
Source: Chan et al (2009).

D. Approved health claims in the European Union (E.U).

The Panel on Diabetic Products, Nutrition and Allergies of the European Commission approved health claims regarding β-glucans as follows: In 2009, the panel affirmed that: "*Regular consumption of β-glucans, naturally present in foods and those forms added to foods, contribute to maintenance of normal blood cholesterol concentrations.*" This claim was based on 3 g/day of β-glucans from oats, oat bran, barley, barley bran or from mixtures of processed or minimally processed β-glucans in one or more servings targeted at adult population with normal or mildly elevated blood cholesterol concentrations (EFSA, 2009). In 2011, the panel affirmed that: *"Consumption of β-glucans contribute to increase in satiety leading to a reduction of energy intake and reduction of post-prandial glycaemic responses and digestive functions"*. This claim was based on 4 g for each 30 g of available carbohydrates.

In 2011 also, the panel also validated a claim that: *"Regular consumption of oat and barley grains' fibre contributes to increase in faecal bulk and maintenance of gut health"* (EFSA, 2011a; EFSA, 2011b).

6. APPLICATIONS OF β-GLUCANS

The physical and physiological properties of β-glucans are of commercial and nutritional importance (Malkki and Virtanen 2001; Vasanthan and Temelli 2008). The increasing interest in β-glucans during the last decade has been largely due to their functional and bioactive characteristics (Cui & Wood 2000). β-glucans are particularly applied in the production of various kinds of functional foods (a conventional food that is consumed as part of a usual diet, and is demonstrated to have physiological benefits and/or reduce the risk of diseases beyond basic nutritional functions, i.e. they contain bioactive compounds) and nutraceuticals (a product isolated or purified from foods that is demonstrated to have a physiological benefit as well as prevention and/or treatment of a disease). Consumer interest and demand for these products considered to be healthier has risen in the last two decades (Havrlentova et al, 2011; Pravst, 2012). However, for effective use of this functional ingredient in this regard, its purity should be exceptionally high. This will ensure specific composition to achieve specific health benefits and remove any form of doubts. Because the cell wall of glucans contains, in addition, starch, a matrix of protein, lipids and mineral elements the issue of extraction techniques to ensure optimum yield, recovery and purity becomes a challenge in order to produce more consistent β-glucans as raw materials in terms of isolation, concentration, molecular weight, water holding capacity and viscosity (*AAFC, 2011; Ahmad et al, 2009; Ahmad et al, 2012b*). Different laboratory scale extraction and purification techniques have been developed by scientists including hot water extraction (Ahmad et al, 2010), enzymatic extraction (Irakli et al, 2004), acidic extraction (Ahmad and Anjum, 2010), alkaline extraction (Li et al, 2006; Wei et al, 2006) and solvent extraction (Bhatty, 1992). However, each technique has its own merits and limitations (Ahmad et al, 2012b).

7. CONCLUSONS

β-Glucans are valuable functional ingredients that possess numerous health benefits with potentials in the food and pharmaceutical industries. They possess multidimensional functional properties and characteristics as stabilizers, viscosity enhancers, fat replacers, gelling agents and plasticizing agents. Their roles in controlling blood cholesterol, blood sugar, immunomodulatory effect and anticarcinogenic activities have been elucidated. Despite the numerous potentials for the present and future applications of β-glucans, challenges still exist in their extraction and purification techniques. Another challenging area is the formulation and molecular weight characterization of β-glucans for new products development. Health claims for β-glucans are supported by scientific evidences. Though approved claims differ from country to country, these claims are now permitted in the U.S.A., U.K., Sweden, and European Union.

8. RECOMMENDATIONS

A better understanding of the role of β-glucans in the formulation of products such as functional foods and nutraceuticals is required through further research. This is in consideration of their rheological, viscosity, and gel formation properties as well as molecular profiles which have multidimensional influences on product formulation. These properties and profiles may affect specific health benefits that are intended to be achieved for specific purposes in such products. Finally, future research efforts should concentrate on the relationship between the physiological benefits and functional properties of β-glucans.

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