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Review

Plant cell wall polysaccharides: Immunomodulators of the immune system and source of natural fibers

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ABSTRACT

The greatest part of the world's population relies on plants as its source of medicines. The crude vegetable drugs or their extracts are utilized, primarily by lay persons either as a form of 'alternative' therapy for the treatment of diseases often of a chronic nature or to attain or maintain a state of improved health. While western developed countries have turned their efforts to promoting and developing a worldwide chemical and pharmaceutical industry, most of the southern countries, including African ones, have neglected their ethnobotanical legacy. Nowadays, the economic crisis and the high costs of most of the modern pharmaceutical based treatments have enhanced a come-back to secular and indigenous medicines. Starting from herbal teas to the development of sophisticated therapies based on plant decoctions or well-purified phytochemical compounds, plant-derived components have been proven to be effective in the prevention or treatment of skin-related pathologies, cancers, metabolic diseases such as obesity and diabetes. These secular treatments include body-washes, decoctions, massages, ingestions, etc.... The aim of this review article is to describe plant-derived cell wall polysaccharides shown to exhibit biological activities. If better characterized, studied and valorised, they may play an important role in health care policy in the world, and more particularly in numerous developing countries in the next decades.

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I. INTRODUCTION

The plant-derived polysaccharides

During photosynthesis, plants convert inorganic carbon into organic forms. This carbon enters several biosynthetic pathways and a broad range of primary and secondary metabolites are synthesized. More than 80% of this carbon is deposited in an extremely rich polysaccharide compartment that surrounds plant cells and is best known as the plant cell wall. Starch, the plant polysaccharide found in the cytoplasm, differs from cell wall polysaccharides in its digestibility by plants, microbes and vertebrate enzymes. The plant cell wall (sometimes called non-starch polysaccharides) consists mainly of cellulose microfibrils, hemicelluloses and pectins [1]. Phenolic compounds and sometimes heavily glycosylated cell wall proteins which are also present in it. The structural complexity of this cell wall from lower and higher plants, as well as the recent advances in genome sequencing program of some model plant organisms (*Arabidopsis thaliana*, *Oriza sativum*, *Chlamydomonas reinhardtii*; respectively Alonso *et al.* 2003 [2]; Matsumoto *et al.* 2005 [3]; Merchant *et al.* 2007 [4], showed that more than a tenth of plant genomes code for enzymes involved in plant cell wall biogenesis. These polysaccharides and glycoconjugates fulfil different biological functions in plants including the control of cell growth and a role of barrier against pathogens. These components consist often of repetitive units of saccharides composed of various sugars including hexoses, pentoses, deoxy sugars, uronic acids.

One of these repetitive units is cellobiose, a [4-β-D-glucose-1,4-β-D-Glucose-1] disaccharide, the elementary brick of the cellulose β-1,4 glucan chain. More complex repetitive units are found with hemicellulosic compounds. These polymers include xyloglucans (substituted β-1,4 glucan chain with various neutral sugars), xylans and arabino/glucurono-/xylans (substituted β-1,4 xylan with arabinosyl or glucurunosyl residues), mannans, galacto/gluco-/mannans (substituted β-1,4 mannan/glucomannan with galactosyl or glucuronosyl residues) and are expressed in the primary and/or secondary cell walls of various organisms starting from algae to dicotyledonous plants. For a detailed overview of the on hemicellulose structure and biosynthesis, we suggest Lerouxel *et al.* (2006) [5], and Moreira and Filho (2008) [6]. *In vivo*, hemicelluloses are believed to interlink cellulose microfibrils, building an important cellulose-hemicellulose network in the cell wall [7]. Various hemicellulose polysaccharides showing different repetitive units (also called oligosaccharides) can be found among plant species. For instance, different hepta- to nonasaccharides defines the structure of xyloglucan [8]. The cellulose-hemicellulose network is embedded in a pectin-rich matrix. The numbers of acidic and neutral monosaccharides found in the chemical composition of pectins, as well as the various types of linkages that bind these monosaccharides to one another, have defined pectin as the most structurally complex polymer in the wall [9]. Indeed, galacturonic acids represent sometimes over 60% of the molecular weight of pectic material, and are found mostly as α-1,4 linked galacturonic acid polymers (or homogalacturonan), often substituted with acetyl residues, or methylesterified. Homogalacturonans can also be substituted with xylosyl residues to form a xylogalacturonan. The most complex pectin structure having a homogalacturonan backbone is the rhamnogalacturonan-II (RG-II). This homogalacturonan backbone is substituted by four different side chains, referred to as chain A-D, and having different structural compositions. These side chains contain some rare sugars like apiose, aceric acid, 2-keto-3-deoxy-D-manno-octulosonic acid (or Kdo). Two RG-II monomers bind together to form an RG-II dimmer, this binding occurs via a cross-linking with a 1:2 borate-diol ester. There is another pectic component which differs slightly from the others previously described. Rhamnogalacturonan I (RG-I) contains a backbone of the repeating [4-α-D-GalacturonicAcid-1,2-α-L-Rhamnose-1] disaccharide. RG-I is believed to interrupt the homogalacturonan pectic backbone and may form with it a continuous pectic chain [10]. RG-I is most often substituted by side chains enriched with arabinose (arabinan chain), or with galactose (galactan chain). A combination of arabinan and galactan chains is sometimes present within the same acidic pectic material, as well as different arabinogalactan (AG) chains varying in the type of linkage found between their arabinosyl and galactosyl residues [11]. Type I arabinogalactan (AG-I) refers to a β-1,4 galactan chain linked to position 2 of the rhamnosyl residue of a RG-I backbone. The β-1,4 galactan chain can be substituted at O-3 by side chains containing 1,5-linked L-arabinofuranose residues, whereas the type II consists of a (1→3)-linked β-D-Gal*p* main chain, substituted at O-6 by 1,6-linked β-D-Gal*p* side chains [12]. While AG-I is specific to pectic polysaccharides, the type II arabinogalactan (AG-II) may also be found associated to them as well as with arabinogalactan proteins (AGPs). In addition to this AG-II moiety, AGPs can also bear smaller arabinan chains [13]. The polysaccharide moiety of these glycoproteins represents up to 90% of the molecular weight of the molecule and their protein backbone is often enriched in hydroxyproline, serine and threonine residues [14]. AGPs specifically react with the Yariv reagent [15, 16]. This interaction occurs between the AG-II moiety of the proteins and glycoside residues attached to the phenylazo ring of the chemical dye [17].

The wide structural diversity of plant cell wall polysaccharides (or non starch polysaccharides) reflects the different mechanisms of action these polysaccharides may use to stop, prevent or heal various infections or pathologies and an abundance of literature has reported that some of their sub-fractions are able to activate the animal immune system and modulate obesity.

II. Immunomodulation of the immune system

Vertebrates have developed a sophisticated immune system which protects them from intruders which can be chemical molecules, pollen, food or whole microorganisms. Immune-stimulating molecules can promote the immune system to an activated state which considerably increases its capacity to fight and eliminate intruders during infection [18]. Among these molecules, plant cell wall polysaccharides are shown to be nonself antigens, heavy molecular weight molecules, structurally complex components which are also partially degradable by host immune system. These criteria qualify almost all plant cell wall polysaccharides as immunogen molecules that are able to activate the vertebrate immune system at different levels, giving them a better means to react efficiently against different kinds of infections [19].

The immune system involves all the mechanisms used by the body for protection from intruders. Two responses, innate immunity and acquired immunity, can be activated for the fight. Innate immunity refers often to the body surface (skin, mucous membranes) as well as internal components including phagocytic cells like macrophages, and other soluble factors released by leucocytes [19]. The term immunomodulation refers to the activation of the immune system involving complement activation. The complement cascade is an important part of innate immune defence [19]. Its involvement contributes to inflammatory responses and enhances immunological defence reactions. Acquired immunity supplements the protection provided by innate immunity and comes into play relatively late. B and T-Lymphocytes are actively involved in acquired immunity. B-Lymphocytes are able to specifically recognize an antigen, including soluble polysaccharide derived-immunogens, via the production of antibodies and the activation of complement. It must also be noted that both innate and acquired responses are not completely independent since complements, which group together a set of soluble or membrane-circulating factors, allow innate and acquired immunity actors to work together.

A range of polysaccharides isolated from higher plants is considered to be biological response modifiers which have been reported to enhance various immune responses like complement activation, lymphocytes proliferation and macrophages stimulation. The use of immunomodulators derived from plants is attractive because it allows the enhancement of host-derived mechanisms while not involving the use of microorganism-specific therapeutics such as antibiotics [20].

1. Immunological activity of pectic polysaccharides

Many naturally occurring pectic polysaccharides from plants, bacteria, lichen and fungi [21] act on human immune system. While the term “acidic polysaccharides” generally refers to pectic polysaccharides, they may be acidic or neutral since their side chains, sometimes enriched in arabinan, galactan or AG side chains, may account for 60% of the polysaccharide molecular weight and may be found free of any galacturonic backbone attachment, but linked to AGPs. In general, the term “neutral polysaccharides”, is mostly associated with hemicellulosic compounds (see section II). Several studies have described the immunomodulatory and mitogenic (proliferation of B-lymphocytes) properties of pectic polysaccharides. These pectic fractions are very often badly characterized and may play a role at different levels, varying from complement fixation to B-cells proliferative activities [22, 23, 24, 25, 26, 27, 28, 20, 29, 30].

a) Immunological activity of acid and neutral pectic polysaccharides

Different types of acid polysaccharides such as RG-I, RG-II and homogalacturonans isolated from plants used in traditional medicine, have been identified for their activities on the complement system [23]. They also interfere with macrophage and lymphocyte activities. Several studies have shown that pectic fractions that have an activity on the immune system are enriched of galacturonic acids and also contain often heavily branched AG-I or AG-II. The first AG isolated and found to have an immunomodulatory effect on the complement system is the AG-II extracted with hot water from the roots of *Angelica acutiloba* [31]. Diallo *et al.* (2003) [26] showed that the pectic polysaccharides isolated from the leaves of *Trichilia emitica* (Miliaceae), a plant used in traditional medicine in Mali, activated the complement system and induced the proliferation of T and B-lymphocytes. The fractions extracted with hot water, a treatment known to isolate mostly pectic extracts, were found to be active on complement system. These fractions contain the acidic RG-I backbone bearing an AG-II side chain which binds to the Yariv reagent. Partial acid hydrolysis with oxalic acid removes mostly the β-1,3 and β-1,5 branched β-1,3 galactosyl side chains. Biological tests prior to and after partial hydrolysis revealed that most of the activities are due to the type II arabinogalactosylated side chain of the RG-I fraction, and the removal of arabinosyl residues by oxalic acid treatment decreased this biological activity. Similar studies on *Glinus oppositifolius* (Aizoaceae), a plant found in western Africa, also showed the activation of complement system by two pectic polysaccharides (GOA1 and GOA2). GOA1 showed a heavily and mixed chains containing AG-I and AG-II linked to RG backbone, while GOA2 had a more classical pectic structure with a polygalacturonan backbone interrupted by RG regions, poorly substituted with AG-II [28]. Both fractions were able to activate the complement system and to induce the chemotaxis of macrophages and T-cells at the inflammation site. Further chemical analyses showed that an RG-I pectic polysaccharide isolated from both GOA1 and GOA2 fractions caused a complement system activation and B-cells proliferation, while a lower activity was associated with the RG-II pectic polysaccharide isolated from the GOA2 fractions [20]. The active extract from *Vernonia kotschyana* (Asteraceae) roots, another medicinal plant used in Mali for the treatment of gastrointestinal disorders and wound healing, is part of a registered improved traditional medicine called Gastrocedal [32]. The polysaccharides extracted from these roots with hot water also show some activity on the complement system. The active fraction is an RG-I polysaccharide with side chains consisting of AG-I and AG-II [27, 33]. While the acidic RG-rich backbone was found to efficiently activate the complement system, the AG-II side chain it carried was shown to have a mitogenic activity.

Taking advantage of specific carbohydrate hydrolases, different researchers have tried to characterize the biologically active motifs associated to the AG-II side chains found in RG-I. Studies on *Biophytum petersianum* Klotzsch (Oxalidaceae), a Malian medicinal plant used to heal various types of illnesses related to the immune system (inflammations, fever, malaria, joint pains, and wounds), showed that, the AG side chains associated to RG-I [29] exhibit an immunomodulatory activity. Potentially active fractions were characterized after enzymatic degradation using *endo*polygalacturonases. Partially characterized released subfractions were able to stimulate various cellular actors of the immune system [29]. Sakurai *et al.* (1998) [34] have shown that the biological activity (activating and anti-ulcer activities) of *Bupleurum falcatum* (Umbelliferae) a Sino-Japanese plant, was associated to RG core substituted with one galactosyl side chain (β-1,3galactosyl chains to which β-1,6-linked galactosyl chains) bearing α-1,5 arabinofuranosyl chains. β-1,6 linked galactosyl residues carrying one terminal Glucuronic acid (GlcA) or 1,4-methylated GlcA, are responsible for the major immunogenic activity. The biologically active AG-II fraction was called bupleuran 2IIc. *In vitro* studies showed that bupleuran 2IIc induces proliferation of B-cells in the absence of macrophages, and the activated B-cells are induced into antibody-forming cells in the presence of interleukin-6 [34]. Another study on *Glinus oppoditifolius*, a plant used in traditional medicine in Mali for the treatment of several diseases, showed that a β-1,3 galactosyl side chain containing a terminal glucuronic acid (GlcA), or a 4-O-methyl-GlcA is responsible for the biological activity. This pectic extract binds to B-cells receptors and induces their proliferation [20].

b) Immunological activity of AGPs

AG-II are heavily branched side chains linked to RG-I pectic polysaccharides, but also to AGPs. Indeed, AG-II may be found associated to the RG-I backbone, linked to AGPs, or free in the wall (maybe cleaved by wall hydrolases *in muro*) and have the ability to bind the Yariv reagent [32, 30]. These common chemical properties make it sometimes difficult to attributes the biological activities found to a particular molecule. Classen *et al.* (2006) [35] showed the immunomodulatory activity of the AGPs of *Baptisia* and *Echinacea* species. These AGPs have an influence on proliferation and the production of immuno-globulin M (IgM) of lymphocytes in mice, the stimulation of nitrite and the production of interleukin-6 by macrophages. Thude *et al.* (2006) [36] showed that the AGP isolated from the juice of the aerial parts of *Echinacea purpurea* bind to the lymphocytes, monocytes and granulocytes of different donors.

Extensive reports of studies showing the anti-complementary activity of many other pectic polysaccharides are summarised in Table 1.

2. Immunological activity of hemicellulosic polysaccharides

Hemicelluloses are neutral polysaccharides which account for approximately 35% of the biomass of annual and perennial plants and hemicellulosic polymers isolated from different plants used in traditional medicine. Like pectic polysaccharides, they present immunomodulatory and immuno-stimulating activities.

Bioactive galactomannan which are hemicellulosic polysaccharides have been described in Fenugreek (*Trigonella foenum-graecum* L). This is an annual leguminoseae herb used as a spice (seeds), or as vegetable (leaves). Fenugreek is an indigenous plant growing in western Asia and in the south of Europe. It is also known for its aphrodisiac properties as well as for its use in treatment of rickets, diabetes, dyspepsia, rheumatism, anaemia and constipation [37, 38], some studies show that galactomannan fractions extracted from Fenugreek exhibited immunostimulatory activity [38]. The *Aloe vera ace* mannan-rich fraction was also found to exhibit immunomodulatory activities [39]. Zha *et al.* (2007) [40] have purified a hemicellulosic polysaccharide (HPS-1B23) (Figure 1) from the stems of *Dendrobium huoshanense*, a plant used in traditional Chinese medicine as a therapeutic agent for curing cataract, throat inflammation, fever and chronic superficial gastritis or as a tonic [41, 40]. HPS-1B23 stimulates the immune system at different levels (stimulation of interferon gamma (IFN-γ) and the secretion of tumour necrosis alpha factors (TNF-α). The active hemicellulosic fraction, enriched with glucose, mannose and galactose, may consist of a mixture of branched galactomannans and galactoglucomannans. Immunological activities were also found on Tamarind (*Tamarindus indica*) seed xyloglucans. These hemicellulosic polysaccharides, consisting of a β-1,4 glucosyl backbone substituted by xylosyl or galactoxylosyl residues have shown several biological activities such as a marked inhibitory effect on the binding of the polyomavirus family (BK) to cells, or immunomodulatory effects on the complement system [42]. Tamarind seed xyloglucans may also induce the secretion of cytokines in various skin-cell lines [43]. Characterization and biological activity tests were recently initiated on

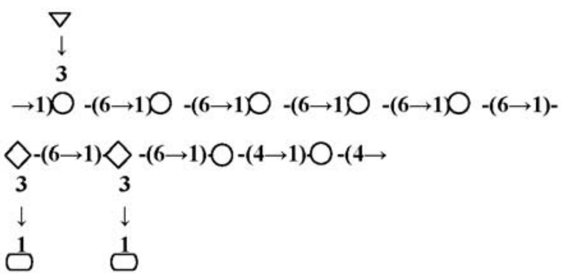

Figure 1. Proposed structure of repeat unit of HPS-1B23 from *Dendrobium huoshanense* as proposed by Zha et *al.* 2007.

Legend: ○ : α-D-Glup, ▽ : OAc, ◇ : α-D-Manp, ▭ : α-D-Gal

Table 1. A few examples of pectic polysaccharides with anticomplementary activity isolated from medicinal higher plants.

Botanical name and part used	Activities and type of structure				References
	RG-I	RG-II	AG-I	AG-II	
Acanthus ebracteatus **Stems**	Complement system	-	-	-	[81]
Angelica acutiloba **Roots**	Anti-tumour Complement system	-	Anti-tumour Complement system	Complement system	[82, 83]
Artemisia princeps **Leaves**	Complement system	-	-	-	[84]
Atractylodes lancea DC **Rhizomes**	Modulation of intestinal Immune system	Modulation of intestinal Immune system	-	Modulation of intestinal Immune system	[85]
Bupleurum falcatum **Roots**	Anti-ulcer Complement system	Anti-ulcer Complement system	-	Anti-ulcer Complement system	[34]
Biophytum petersianum **Aerial parts**	-	-	Complement system	Complement system	[29]
Calendula officinalis **Flowers**	-	-	Phagocytose of granulocytes	-	[86]
Entada Africana **Roots**	-	-	Complement system	Complement system	[25]
Glinus oppositifolius **Aerial parts**	B-cell proliferating Complement system	-	B-cell proliferating Complement system	B-cell proliferating Complement system	[20, 28]
Panax ginseng **Leaves**	Complement system	Intestinal immune system Modulating activity	-	Complement system	[87, 88, 22]
Piper nigrum **Seeds**	-	-	-	Complement system	[89]
Phellodendron chinese SCHNEID **Roots**	Anti-tumour activity	-	-	-	[90]
Sedum telephium **Leaves**	Complement system Activation of macrophages	-	-	-	[91]
Tanacetum vulgare L **Florets**	-	-	-	Activation of macrophage/monocyte Complement-fixing	[92]

Table 1 continued..

Tinospora cordifolia **Stems**	Activation of B-cells	-	-	-	[93]
Thymus vulgaris **Leaves**	Complement system	-	-	-	[94]
Trichilia emitica **Leaves**	-		-	- Complement system	[25]
Urtica dioica **Roots**	Increase in the proliferation of the lymphocytes	-	-	-	[95]
Vernonia kotschyana Sch.Bip.ex Walp **Roots**	Immunomodulation Complement system	-	Immunomodulation Complement system	Immunomodulation Complement system	[27]

polysaccharides from *Fleurya aestuans* (Urticaceae), a Gabonese medicinal plant used as an antipyretic, antirhumatic and diuretic and for wound-healing [44]. The alkaline hemicellulosic fractions were fractionated into xyloglucan-rich and acid xylan-rich fractions. Both fractions showed immunostimulatory activity on B-cells. The tests were performed on human blood cells using different concentrations for both extracted hemicellulosic subfractions (1, 10, 50 and 100 µg.mL^{-1}). When treated respectively with xyloglucan-rich and acid xylan-rich fractions, in the presence of *Staphylococcus aureus cowan* A, we found an incorporation rate of tritiaced thymidine between 45000 and 61000, and between 45000 and 100000 in human B-cells. (Figure 2) (Aboughe-Angone *et al.* unpublished). Other hemicellulosic polysaccharides having immunological activity are summarised in the Table 2.

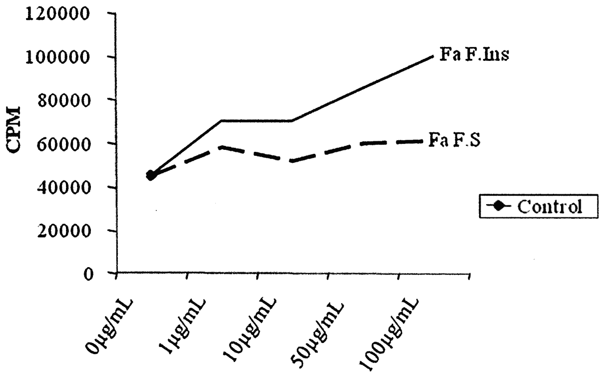

Figure 2. Schema of the proliferation B-cells induces by the hemicellulosic polysaccharides rich fraction xyloglucans (F. XyG) and rich fraction acidic xylans (F. Xylans).

3. Immunological activity of sulphated polysaccharides

Several sulphated carbohydrate polymers (mostly found in lower plants like algaes) were found to be active against various viral infections including important human pathogens such as human immunodeficiency virus, herpes simplex virus, human cytomegalovirus, dengue virus and respiratory syncytial virus [45, 46]. Sulphated polysaccharides are isolated from algae extracts. Their biological activities vary with the molecular size of the polysaccharide, the composition, the

Table 2. Example of hemicellulosic polysaccharides with immunological activity isolated of a few medicinal plants.

Botanical name and part used	Polymers type	Activities	References
Aloe Vera	Acemannan	- Immunomodulatory activity	[39]
Echinacea purpurea **Aerial parts**	Xyloglucan	-Stimulation of macrophages and production of interleukine-1	[96]
Ganoderma lucidum	β-Glucan	- Induce tumour necrosis	[97]
Libyan dates (*Phoenix dactylifera* L.) **Fruits**	β-Glucan	- Anti-cancer	[98]
Plantago asiatica **Seeds**	Glucurono-arabinoxylane	- Complement System	[31, 99, 100]
Plantago major **Seeds**	Heteroxylan	- Complement System	[101]
Poria cocos sclerotium **Entire plant**	β-Glucan	-Anti-tumour	[102]
Rhynchelytrum repens (Wild) **Entire plant**	β-Glucan	-Hypoglycaemic activity	[103]
Tamarindus indica **Seeds**	Xyloglucan	- Immunomodulatory activity - Proliferation of cytokines	[43, 42]
Trigonella foenum-graecum L	Galactomannan	- Immunostimulatory activity	[38]

Table 3. Some sulfated polysaccharides with antiviral activity.

Botanical name	Polymers type	Activities	References
Agardhiela tenera	Sulfated Galactan	VIH1-2 and HSV1-2	[47]
Gayralia oxysperma	Sulfated heterorhamnan	herpes simplex virus (HSV)	[104]
Gigartina aciculaire and Gigartina pistillata	Carrageenan	VIH1-2 and HSV1-2	[47]
Navicula directa	Sulfated Polysaccharide (Naviculan)	VIH-1 and HSV1-2	[52]
Nothogenia fastigiata	Xylomannane	VIH1-2 and HSV1-2	[47]
Porphyridium sp.	Sulfated Polysaccharide	HSV1-2	[105]
Sargassum alga	Sulfated Polysaccharide	Herpes simplex virus (HSV1-2)	[106]
Scinaia hatei	Sulfated xylomannan	HSV	[107]
Stoechospermum marginatum	Sulfated fucans	HSV1-2	[53]

sulfate group position, the type of linkage and molecular geometry [47, 46]. It is also shown that the sulphated polysaccharides may also exhibit anticoagulant, antithrombotic, anti-inflammatory and antitumor properties [48, 49, 50, 46]. The antiviral activity of the sulphated polysaccharides is based on the formation of similar complexes that block the interaction of the viruses with the cells. Correlations are established between different structural parameters and antiviral activity [51]. Sulphate groups require the inhibition of anti-HIV activity inhibition and the potency increases with an increase in the degree of sulphation and the molecular weight of the polysaccharide [47, 46]. Mohsen *et al.* (2007) [46] showed that hot water-soluble sulphated polysaccharides (SP) isolated from the brown algae *Surgassium latifolium*, possess an antiviral activity against HSV-1 and HAV viruses. The fractionation and characterisation of the SP-III sulphated polysaccharide enriched with glucuronic acid, mannose, glucose, xylose and fucose exhibit that antiviral activity. Lee *et al.* (2006) [52] also show that a specific sulphated polysaccharide called naviculan, isolated from a diatom. *Navicula directa* shows an antiviral activity against the types 1 and 2 herpes simplex viruses, and the influenza A virus. Naviculan also shows an inhibitory effect on cell–cell fusion between CD4-expressing and human immuno-deficiency virus (HIV) gp160-expressing cells that was used as a model system of infection with HIV. A sulphated fucan-containing fraction isolated from the brown seaweed *Stoechospermum marginatum* collected from the Arabian Sea also has an inhibitory activity on herpes simplex virus type 1 and type 2 in *Vero* cells, [53]. Other sulphated polysaccharides with antiviral activity isolated from many other algae extracts are summarised in Table 3.

III. Dietary fibre and metabolic diseases

Polysaccharides are able to interact with other polymeric materials, including other polysaccharides, proteins and starches, either modifying each other's properties or providing a giving synergistic effect to increase viscosity or cause gelation, phase separation and other physicochemical phenomena. In recent years, much attention has been drawn to pectic polysaccharides as they have been shown to display various pharmacological activities both *in vitro* and *in vivo*, but focus has especially been on their ability to modulate immune response [23, 27, 33].

The term "dietary fibre" was introduced by Hipsley in 1953 [54] and it regroups the non-digestives constituents of foodstuff. The meaning of the term was then extended to include all non-starch polysaccharides, including those obtained from plant cell walls such as pectic polysaccharides and cellulose residues that are resistant to human intestinal enzymatic digestion [55]. Dietary fibres originating from plant cell walls are mostly water-soluble and include plant exudates (gum), such as Arabic gum, Ghatti gum, Tragacanth gum and Karaya gum and mucilages produced by the epidermis of the seeds of certain species [56]. They also include soluble polysaccharides produced by microorganisms such as Gellan gum, Xanthan gum and Curdlan. More recently, the definition has been extended to include non-digestible oligosaccharides such as fructans, including inulin and other oligofructoses, resistant starches and synthetic polymers such as polydextrose [57, 58]. The American Association of Cereal Chemists adopted the following definition: “Dietary fibres are the edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human intestine with complete or partial fermentation in the large intestine” [59]. They promote beneficial physiological effects including the management of obesity, diabetes, laxative, and/or blood glucose attenuation.

The gastrointestinal tract is heavily populated with bacteria, mainly the strictly anaerobic ones. Most of these organisms are benign to the host; however, certain gut species are pathogenic and may be involved in the onset of acute and chronic disorders [60]. Due to their chemical structure, the polysaccharides are substrates that can only be consumed by a limited number of bacteria, thus stimulating their growth. Among the group of bacteria present in the gastrointestinal tract, the bifidobacteria and lactobacilli are those that mostly utilize oligosaccharides, being considered as the only microorganisms able to beneficially affect the host’s health [61, 62].

Obesity, which is defined as an excess in weight and a body mass index superior to 30% has become in the past few years a major public health problem in our society. Obesity and obesity related type II diabetes are typical diseases of the modern Western society. Current recommendations for the management of these conditions include an increase in dietary fibre intake [63]. Recent studies have shown that obesity is characterised by a subchronic inflammatory state [64, 65] that is justified by an increase in the levels of many circulatory inflammatory markers like IL-6, TNF haptoglobin [66]. In relation with the pathological consequence of obesity and the strategies of treatment, the hypothesis according to which dietary fibres could have a regulatory effect on satiety or act as a physiological obstacles to food intake and energy supply were developed.

Fibbers can likewise influence the rheological properties of the gastrointestinal content than the processes of digestion and absorption [67]. They essentially carry out physical action in the stomach and small intestine. Soluble fibres like β-glucanes increase viscosity contributing to slowdown the emptying of gastric contents [68]. The presence of viscous polysaccharides in the small intestine affects the interaction of food with digestive enzymes, consequently reducing the speed of digestion of carbohydrates [69]. An increase in the viscosity of the digestive content equally slows down the absorption rate of nutrients. In another way, these fibres could have an effect on blood cholesterol. In fact, fibre has the ability to bind with bile acids and prevent its reabsorption into the liver, thus inhibiting cholesterol synthesis [70]. Arabic gum, natural carbohydrate exudates from *Acacia senegal* and *Acacia seyal* trees in Africa, rich in AGPs, is not ingested in the small intestine. It has therefore applications to reduce plasma glucose and serum cholesterol [71]. A study on five healthy human volunteers taking 25 g/day of acacia gum shows a significant reduction in total serum cholesterol concentrations [72]. It is also assumed that changes in the concentration of serum cholesterol have been related to changes in intestinal microflora [73].

In the stomach, while activating the excretion of gastric acid and digestive hormones, they increase the impression of satiety and in this way could contribute in limiting obesity [74, 69]. A relationship exists between the site of degradation and the type of polysaccharide degraded. Soluble β-glucanes and arabinoxylanes are preferentially degraded at the level of the caeco-colon. Among the functional oligosaccharides, short chainfructo-oligosaccharides (FOS), given at the dose of 10% in the diet of rats for a few weeks reduces hepatic triglyceride content, postprandial glycemia and triglyceridemia in normal rats, lessens hepatic steatosis and fat mass development in obese Wistar rats fed with high fat diet. This phenomenon could be partly explained by a satiatogenic effect of FOS [75, 76].

Other insoluble polysaccharides could equally be degraded in the large intestine; this is the case of linear xylanes. The kinetics is slow but the degradation is total. However, xylanes and arabinoxylanes from lignified tissues are more resistant [77]. The bacterial fermentation of certain constituents of fibres leads to the formation of many products which play an important role in the physiology of the large intestine and in metabolism [78].

Diabetes mellitus is a common chronic metabolic disorder involving carbohydrate, fat and protein metabolism and characterized by glycosuria and hyperglycemia. The treatment aims at regularizing blood glucose level by the use of hypoglycaemic agents, α-glucosydase inhibitors, sugar-restricted diets, and complex carbohydrate (fibber) preparations which delay the absorption of glucose from the gut [79]. Recent works suggested that complex polysaccharides could interfere with the receptor signal transduction pathway of insulin, notably with Protein Tyrosine Phosphatase (PTP1B), a potential therapeutic target of type 2 diabetes located on the cytosolic surface of the endoplasmic reticulum. Protein tyrosine phosphatases regulate the insulin signaling by mediating the balance between insulin receptor phosphorylation and dephosphorylation. Recently, Mao *et al.* (2007) [80] showed that Astragalus water-soluble polysaccharides increase insulin sensitivity by decreasing the over expression of PTP1B in type 2 diabetes animal models.

GENERAL CONCLUSION

Plants remain the most abundant source of foods, phytomedicinal remedies and natural composites able to meet numerous needs of human beings. We showed here that plant-derived cell wall polysaccharides display a wide variety of structure. Several of these molecules have biological activities and may be helpful to prevent or heal various infections or diseases. In this respect, polysaccharides are still less studied and valued, when compared to some others plant molecules like alkaloids for instance. In some places, particularly in southern developing countries including African countries, the identification and *modus operandi* of these different medicinal plants are known and belong to traditional healers. During the last decade, different projects aiming at chemically and biologically characterizing bioactive plant cell wall polysaccharides found in southern countries have started and become widespread among almost all of these countries, especially in Africa. Completed works represent a very small percentage of the task, regarding the richness of African biodiversity. Sustained efforts, may also be involving the development of new analytical techniques, must also be made to completely purify the bioactive motifs among a relatively broad polysaccharidic fraction or sub-fraction, shown to have biological activity. Progress and completion of this work may allow those developing countries to develop and promote their own medicinal therapies based on bioactive cell wall polysaccharides. Similar developments have been previously undertaken by different Asian countries including India, China and Japan.

The recent identification of almost all the genes involved in cell wall polysaccharide biosynthesis has increased our understanding of this process. More interestingly, resources are available among different lower and higher plant species. For instance, The CAZy database (Carbohydrate Active enZymes; www.cazy.org)F compiles all the genes from different plant organisms having a proven enzymatic activity. Understanding the molecular mechanisms underlying the biosynthesis of these components has recently boosted biotechnological research in several domains of plant research, including plant biomass derived biofuel, agriculture, etc. The opportunity could also be taken to develop biotechnological approaches to increase the availability of plant cell wall carbohydrate components showing a promising biological activity during the treatment of various diseases. Similar approaches, often coupled to organic chemistry synthesis, have been followed before in the past to produce other plant-derived metabolites at large scale. In contrast to other plants metabolites, the structural complexity does not easily allow for the development of an organic chemistry-based approach. Only a large scale production of these active carbohydrates can meet the needs of a numerous population and the development of phytochemical pharmaceutical industry. The extensive screening of potential and uncharacterized bioactive polysaccharides from southern countries, along with the ethnobotanical and ethnopharmacological legacy, their complete purification and chemical characterization, and the availability of biotechnological resources may allow us to write a new story on plant-based medicinal therapy.

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