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Review

Rasayana properties of Ayurvedic herbs: Are polysaccharides a major contributor

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ABSTRACT

Rasayana constitutes a very important class of Ayurvedic herbs, which acts as rejuvenators and tonic. Despite intensive research on evaluating the medicinal basis for the purported medical benefits of Rasayana herbs, still a specific chemical guiding principle for the characterization of these herbs in one single category is unclear. Here we explore the possibility that polysaccharides play a key role in Rasayana properties exhibited by medicinal plants. Further on this could be a possible field for exploration for a common factor present in some of the Ayurvedic herbs. The present review covers a literature spanning from 1956 to 2011. Some translations of traditional Ayurvedic texts dating back to the first century AD have been referred to as well. In our assessment of the present literature and studies carried out it is presupposed that the presence of benevolent plant polysaccharides must be one of the important features symbolizing a common effectiveness in most of the Ayurvedic Rasayana herbs. Of the many plant metabolites polysaccharides have not so far been considered and studied effectively compared to other secondary metabolites like saponins, alkaloids, etc. Although all the results reported until now suggest a major contribution of polysaccharide towards the maintenance of physiological homeostasis, which is the guiding principle of Rasayana therapy. The present review is an attempt to find a connective link between the concept of Rasayana and well-being; and the role of plant polysaccharides. Lack of clinical information on number of polysaccharides showing promise is a limiting factor for a complete understanding. It is also important to carry out a molecular interaction study to understand the behavior of polysaccharides discussed in the present review.

Contents

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1. Introduction

Human body is prone to a number of stresses and stressors leading to a dilapidation of normal cellular mechanism. Ayurveda the traditional Indian system of medicine holds a specialized class of herbs which have been purported with numerous claims and benefits for rejuvenating the whole functional dynamics of the human body (Ghosh, 1981). Life or Ayus (symptomatically the life span) is the primary subject matter of Ayurveda (Ali, 1997; Nordstrom, 1989). The concept of Rasayana and the usage of herbs as preventive agent against various infections and diseases date back to the time of Sushruta (around 4000 B.C.) (Ali, 1998; Rege, Thatte, & Dahanukar, 1999). It is from this period; the herbs of Ayurveda have been subjected to clinical utilization and have been valuable in combating health related problems. The whole dynamics of Rasayana involves a maneuvered modulation of the neuro-endocrino-immunological system for bringing about a balance or a state of physiological homeostasis making the body adaptable to various stresses (Govindarajan, Singh, & Rawat, 2007; Nicolson, 2010).

The locum nutraceuticals and functional food are modern day terms signifying the growing interest of the modern world in leading a healthy and disease free life style. Nevertheless, much before the concept of immunity or microbial diseases was known, a large number of plants were used by the traditional healers in Europe and Asia (especially China and India) for rejuvenation therapy as well as treatment against chronic ailments (Balazs, 2010; Chan, Chan, & Shek, 1994; Khor, Duraisamy, Loh, & Green, 2006; Nicolson, 2010; Singh & Singh, 1991). The disease preventive and health promoting approach of Ayurveda is gaining increasing prominence in the contemporary world. An interesting example of the renewed interest is the flooding of health and fitness market with numerous herbal products as nutraceuticals, dietary supplements, etc. (Bopana & Saxena, 2007; Chauhan, Sharma, Thakur, & Dixit, 2010; Ojha, Sahu, Muruganandam, Singh, & Krishnamurthy, 2010; Rege et al., 1999).

In terms of alternative therapies for health benefits, the most befitting example could be drawn from the concept of Ayurvedic Rasayana. On a literal basis Rasayana can be split as Ras (elixir) and Ayana (home or path), thus signifying the path or direction of the elixir of life. Therefore, according to the traditional practitioners of Ayurvedic therapy the herbs of Rasayana category act by modulating and balancing the whole physiological functioning (Chauhan et al., 2010; Ojha et al., 2010).

1.1. Rasayana therapy at a glance

Rasayana therapy is a complete medical procedure, which requires a lot of proficiency and skill for practicing. The first and foremost requirement is a very restricted schedule of diet and a detoxification of the whole body (Puri, 2003b). The process of cleansing the body and making it free from toxins utilizing the five openings of the human body is known as 'Panchakarma' a group of five basic activities considered mandatory for an effective Rasayan chikitsa. Followed by cleansing, the body is served with various Rasayana herbs in the form of decoctions or powder to replenish the lost nutrients and to enhance virility. In the present scenario, the whole process seems to be quiet tedious and time consuming and so a more rational approach for proper utilization of Rasayan herbs is requisite for the modern society (Conboy, Edshteyn, & Garivaltis, 2009; Mahdihassan, 1981; Puri, 2003b; Sharma, Chandola, Singh, & Basisht, 2007; Shukla, 1971).

The concept of well-being has become increasingly important and this comes with the cognizance that there is more to health than the absence of diseases (Sims, 2010). This is also the guiding principle of the concept of functional food although from a traditional perspective. Rasayana therapy is an age old, time tested practice, involving usage of such herbs and herbal constituents not only for alleviating diseases but also improving the quality of life (Ali, 1998; Kumar, Kuttan, & Kuttan, 1999; Puri, 2003b; Sharma, Hanna, Kauffman, & Newman, 1995; Shukla, 1971).

A number of herbs belonging to the category of Rasayana have been scientifically studied and validated for their effect on the immune system, endocrinological benefits, antioxidant properties, memory and learning behavior improvement, etc. Although the concept is well understood and practiced, there is a need to rationalize the approach and analyze the possible phyto-chemical constituents contributing to the majority of actions and activity in these herbs (Chopra, 2000; Govindarajan, Vijayakumar, & Pushpangadan, 2005; Scartezzini & Speroni, 2000; Singh, Narsimhamurthy, & Singh, 2008; Ven Murthy, Ranjekar, Ramassamy, & Deshpande, 2010). The biological effects of Ayurvedic Rasayana herbs have been described in detail in Fig. 1. Classification of immunomodulatory Rasayana polysaccharides into different categories has been discussed in detail in Fig. 2.

In the present review, we summarized the main role played by some of the distinctive polysaccharide present in these herbs and correlate them with the attributed ethno-pharmacological claims. Consequently a review of individually selected plants has been illustrated with the possible contribution of polysaccharides from the herbs and summarized in the form of a table.

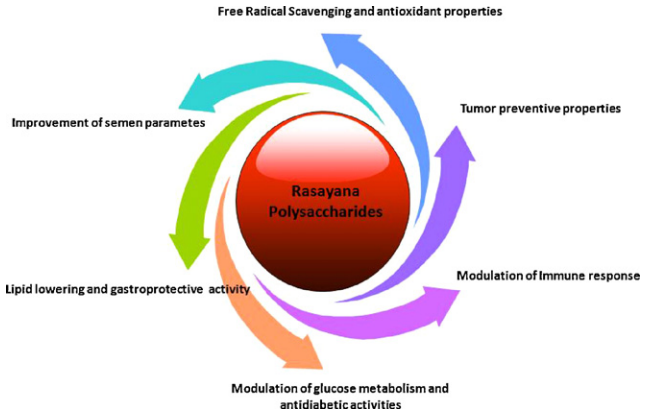

Fig. 1. Biological effects of Ayurvedic Rasayana herbs illustrated or documented so far.

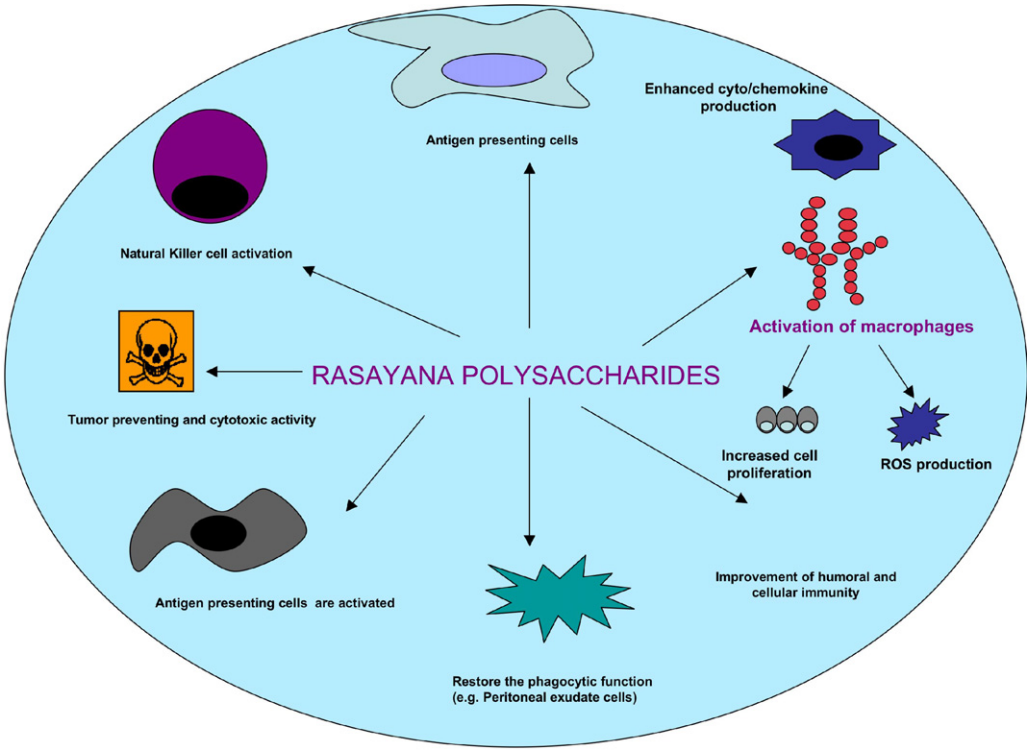

Fig. 2. Effect of Rasayana polysaccharides on immune function.

2. Methods

A thorough search of traditional Ayurvedic literature and its translation in English language spanning a time frame of past 100 years was carried out. The modern literature validating the claim for the use of polysaccharides in Rasayana therapy covers a time span of 1956 to 2011 using various databases and search engines *viz.* Google Scholar, Scifinder, Scopus, etc.

3. Polysaccharides and Rasayana therapy

During the last decades numerous carbohydrate polymers have been shown to be responsible for biological effects, either by exhibiting the effect themselves or by inducing effects via complex reaction cascades (Ven Murthy et al., 2010; Wang & Quinn, 2010). Polysaccharides can have number of effects including anti-inflammatory, immunostimulating, complement activation, antithrombotic, antidiabetic and infection protectant activity and many more (Thakur, Bag, et al., 2009; Thakur, Bhargava, Praznik, Loeppert, & Dixit, 2009; Thakur, Chauhan, Bhargava, & Dixit, 2009; Xiao, Liang, & Liu, 2002; Yeaman et al., 2001; Zjawiony, 2004). Diet and dietary substances have been known for being a contributor in immunomodulation in biological milieu (Di Luigi, 2008; Johnston & Zhou, 2007; Ruggeri, Straniero, Pacifico, Aguzzi, & Virgili, 2008; Zjawiony, 2004). In contrast to the existing reports on functionality of dietary substance the non-dietary components are not so very well established (Lietz, Lange, & Rimbach, 2010). The components involve phytochemicals and prebiotics. The prebiotic substances include polysaccharides (inulins, mannans, pectins, arabinogalactans, etc.) (de Palencia et al., 2009; del Giudice & Brunese, 2008; Wichers, 2009). Most polysaccharides especially fructans and mannans are derived from higher plants. They are relatively nontoxic and do not cause significant side effects, which is a major problem associated with immunomodulatory bacterial polysaccharides and synthetic compounds (Michel et al., 1998; Mori et al., 1989; Shanmugam et al., 2008; Sullivan, Laba, Moore, & Lee, 2008). Thus, plant polysaccharides are ideal candidates for therapeutics with immunomodulatory, anti-tumor and wound-healing action (Mythilypriya, Shanthi, & Sachdanandam, 2008; Schmid et al., 2009; Speranza et al., 2009).

A number of Ayurvedic Rasayana herbs have been advocated as immunomodulatory in nature (Chopra, 2000; Gaddipati et al., 2004; Govindarajan et al., 2005; Inaba, Mirbod, & Sugiura, 2005; Jagetia, Malagi, Baliga, Venkatesh, & Veruva, 2004). Evidently the whole concept of Rasayana involves the modulation of neuro-endocrino-immunological system. Therefore an evident role of polysaccharides in modulation of immune system could be one of the guiding features for the Rasayana type action of most of the herbs. In depth study by Wagner et al. successfully contributed to the elucidation of the auto-regulatory mechanism involved in the functionality of Ayurvedic Rasayana herbs (Sendl, Mulinacci, Vincieri, & Wagner, 1993; Steinmuller et al., 1993; Sullivan et al., 2008; Wagner & Hauss, 1973; Wagner et al., 1984).

3.1. Types of polysaccharides in Ayurvedic plants and their medicinal benefits

Structural carbohydrates and the non-structural carbohydrates also known as storage carbohydrates are the two broad classifications used for polysaccharides in plant kingdom (Pontis, 1966; Pontis, Gonzalez, & Etxeberria, 2002; Pontis & Wolosiuk, 1972). The structural carbohydrates engender components like cellulose, glycan, pectin, etc. while the non-structural carbohydrates include sucrose, starch and fructan (Thakur & Dixit, 2005).

3.1.1. Fructans

Fructans are a distinct group of non-structural carbohydrates that has been attributed with numerous physiological benefits. Inulin type fructans ($2\rightarrow1$ linked) are the prototypes for most of the studies carried out on medicinal aspects so far (Houston & Burrell, 1948; Thakur & Dixit, 2005). Amongst the most benefited physiological functions in the body the gastrointestinal functions

are surely the primary end points. Colon is the most benefited organ with fructan consumption (Kelly, 2008). Colon is mainly responsible for absorption of salt and minerals as well as microbial fermentation and maintenance of benevolent microbial flora (Molbak, Thomsen, Jensen, Bach Knudsen, & Boye, 2007). These features are also attributed as prebiotic effects and inulin type fructans have been found to be the most potential prebiotics. The inulin type fructans escape the digestion in upper gastrointestinal tract (GIT) and reach the large intestine virtually intact, this provides them with the advantage of being fermented in large intestine where the potentially benevolent microflora (*viz.* lactobacilli, bifidobacteria, etc.) could thrive upon the nutrition received in the form of fructan (Abrams et al., 2007; Awad, Ghareeb, & Bohm, 2011; Bosch et al., 2008; Falony, Calmeyn, Leroy, & De Vuyst, 2009; Reddy, Hamid, & Rao, 1997; Tako et al., 2008; van de Wiele, Boon, Possemiers, Jacobs, & Verstraete, 2007). Rasayana herbs having a major proportion of fructans and providing health benefits include Shatavari (*Asparagus racemosus)*, Safed Musli (*Chlorophytum borivilianum*), Akarkara (*Anacyclus pyrethrum*), Munjataka (*Orchis latifolia)*, Lahsun (*Allium sativum*), Onion (*Allium cepa*) (Baumgartner, Dax, Praznik, & Falk, 2000; Das & Das, 1977; Jacobsen et al., 2006; Matsuura et al., 1996; Narasimhan et al., 2006; O'Donoghue et al., 2004; Pompei et al., 2008; Poulsen, Molck, & Jacobsen, 2002; Thakur, Bhargava, et al., 2009).

Fructans in general are found capable of being able to modulate the polyamine concentration in the cecum of rats. The data reported also suggest their involvement in cecal enlargement and enhancement of hepatic lipid metabolism (Delzenne & Kok, 2001). Fructans have long been subjected to tests on their effect on the mineral absorption (Daubioul et al., 2002; Kok, Roberfroid, & Delzenne, 1996; Roberfroid & Delzenne, 1998). Studies so far have revealed that inulin-type fructans enhance Ca^{2+} and Mg^{2+} absorption in growing rats and increase ionic iron and Zn^{2+} balance without having a significant effect on Cu^{2+} bioavailability (Abrams et al., 2007; Roberfroid, Cumps, & Devogelaer, 2002; Tako et al., 2008). Study on human volunteers has revealed that the fructan type oligomers have a positive effect on the overall absorption of Calcium and the maintenance of Calcium balance. The findings of various trials on mineral absorption and role of fructans also show that regular intake of even modest amount of inulin type fructans significantly increases the absorption of Ca^{2+} and Mg^{2+}. Similarly, inulin type fructans do not only assist in improving the uptake of minerals but are also substantially involved in improving the bone mineralization as well as bone health (Abrams et al., 2007; Coudray et al., 2005; Nzeusseu et al., 2006). Coudray et al. (2005) clearly demarcated the role of all the different type of fructans on mineral absorption. The study also appraises of a synergistic effect of oligofructose and high polymer combination fructans to have a synergistic effect on the Ca^{2+} and Mg^{2+} absorption. Coxam (2005) reported that inulin type fructans when administered along with isoflavones can result in better availability of phytoestrogens and could provide a state of the art perspective in the management of osteoporosis.

Numerous Ayurvedic herbs are known to be effective in promoting better mineral absorption. They are beneficial in osteoporosis and associated symptoms, therefore in our opinion a contribution of fructans present in Rasayana herbs can be considered as an important contributing factor for the improvement of mineral absorption and associated prevention of osteoporosis.

A lot of plant polysaccharide have been reported until recently for having immunomodulatory property. Recent data now provide initial evidence that inulin and oligofructose modulate functions of the immune system which include concentration of IgA in the ileum and cecum, natural killer cell cytotoxicity as well as splenocyte enhanced natural killer cell cytotoxicity in gut associated lymphoid tissue (GALT) (Abrams et al., 2007; Roberfroid, 2005; Roberfroid & Delzenne, 1998). Numerous plants like *C. borivilianum*, *A. pyrethrum*, *Articum lappa*, *A. racemosus*, *Matricaria maritima*, *A. sativum*, *Vernonia kotschyana* rich in inulin type fructans have been reported to possess potent immunomodulatory activity along with other beneficial effects (Poulsen et al., 2002; Thakur, Connellan, Deseo, Morris, & Dixit, 2010).

Recently fructans and oligofructose have also been demonstrated for possessing potent antioxidant activity, which was elucidated in rats against streptozotocin induced oxidative stress. Similarly, a lot of work on fructans suggests their role as antidiabetic agent as well (Narasimhan et al., 2006).

Fructans have also demonstrated a lot of potential in improving the bowel habits and relieving constipation (Kaur & Gupta, 2002). Administration of oligofructose and inulin could improve constipation in 9 out of 10 subjects. A significant improvement in stool frequency in patients reporting one stool every 2–3 days was also observed (Roberfroid, 2007). Immunological studies on fructan have shown tremendous potential. Fructans have been capable of eliciting intestinal immune function in rats. The study involved the synergistic combination of prebiotic fructan along with probiotic components like bacterial strains of intestinal flora. The overall effect on the intestinal immune function showed great promise for further exploration (Brighenti, Casiraghi, Canzi, & Ferrari, 1999; Kleessen, Sykura, Zunft, & Blaut, 1997; Roberfroid, 2005).

The effects of inulin-type fructans on triglyceridemia have been studied in both animals and humans. In rats, a decrease in serum triglyceridemia (in both the fed and the fasted state) was consistently reported in several studies; in healthy humans, only fasting triacylglycerol was measured, and it was modified in only one study. The effect of fructan on triglycerol metabolism has been found to be a result of two mechanisms. Firstly, they modify the glucose or insulin concentration as an initial effect of enhanced lipogenesis resulting due to dietary modulation. Secondly the effect is elicited by the production of short chain carboxylic acids *viz.* acetate and propionate resulting in fatty acid synthesis inhibition and also acting as substrate for lipogenesis substrate (Abrams et al., 2007; Coudray, Feillet-Coudray, Gueux, Mazur, & Rayssiguier, 2006; Coxam, 2007; Daubioul et al., 2002).

Studies regarding effect of fructans on carcinogenesis are still under experimentation but published data does suggest that there is a potential in these components for exploring their possibilities in treatment of colon cancer (Reddy et al., 1997). In one of the recently published reports Pool-Zobel (2005) reviewed the role of inulin type fructans in reducing colon cancer risk. In human studies, the butyrates and other products of fermentation of inulin inhibited cell growth, modulated differentiation and reduced metastasis. Based on the assessments observed so far it can be ascertained that colon cancer prevention and its relapse is a facet of fructan metabolism *in vivo*. In our opinion metabolic profiling of fructans in general and those present in Rasayan plants on a more special basis provides an interesting facet for the nutritional prevention of carcinomas especially colon carcinomas.

3.1.2. Glucans

The α (1 → 4) glucan from *Tinospora cordifolia*, a very important Rasayan plant commonly known as Guduchi, is amongst the first glucans from Ayurvedic herbs reported to possess potent immunostimulatory effect. Nair, Melnick, Ramachandran, Escalon, and Ramachandran (2006) reported an immunostimulating signaling mechanism of the novel (1,4)-α-D-glucan by activation of macrophages via TLR6 signaling, NF-κB translocation and cytokine production. In further research carried out by Leyon and Kuttan (2004) the tumor inhibitory property against B16F-10 melanoma cells by the glucans from *T. cordifolia* was illustrated in a mice model. *T. cordifolia* is a well-studied Ayurvedic plant with a number of clinical recommendations still a systematic clinical trial reporting the effectiveness of polysaccharide fraction clinically is missing.

As a future research path it would be beneficial to carry out a systematic placebo controlled clinical studies to substantiate the claims associated with *T. cordifolia* polysaccharides.

Ocimum sanctum also known as tulsi in Ayurveda is one of the revered herb with number of beneficial effects. Major polysaccharides of *O. basilicum* exhibiting biological effectiveness were found to be β 1 → 3 linked glucans. Wagner (1999) reviewed various effects of water soluble extracts of *O. basilicum* and it appears that the glucans were a major contributor in modulating the immune system as well as liberation of adrenocorticotropic hormone (ACTH) in primary pituitary cell culture (Wagner, 1999). Ghosh and co-workers suggested a possible role of glucans from *Crinium* species in rendering anti-allergic properties and glucans in combination with phosphatidyl-choline were highly useful in preventing degranulation of mast cells. This observation seems to provide evidence towards the multivalent role of glucans as disease protective agents.

Although the major glucan source remains to be the bacterial cell wall (Zvetkova, Wirleitner, Tram, Schennach, & Fuchs, 2001) growing evidence and further studies would clearly provide ample information towards the role of plant derived glucans in providing health benefits. It is worth mentioning here that the glucans from plant sources have been scantily identified and research on their pharmacological utility is sporadic. As a future prospect, evaluation of glucans in lesser studied Ayurvedic plants would surely add to the understanding of their role on immunomodulation.

Some 1 → 3-β-D-glucans like the ones found in *Hordeum vulgare* Linn. known as Java in vernacular are emerging as potentially valuable therapeutic agents. They have anti-bacterial and anti-viral effects, they are believed to stimulate blood coagulation, and they are reported to accelerate the healing of wounds. In addition, (1,3)-β-D-glucans have attracted attention as carcinostatic agents and as immunomodulators in human immunodeficiency virus therapy (Rampitsch, Ames, Storsley, & Marien, 2003).

3.1.3. Acetylated glucomannans

Glucomannans are valuable storage polymers found in plants from different plant families. Salep mannan isolated from Salep tubers is one of the earliest known mannans in the field of medicine. This mannan was later shown to be an acetylated glucomannan where both monomers were linked β (1 → 4), and the acetyl groups were located on different positions on the polymer. The structural facets have been reviewed by Smestad-Paulsen (2002). Some of these orchids, which are also used as Rasayana, are *Dactylorhiza incarnata*, *Dactylorhiza maculata*, *Gymnodenia cocopsea* and *Orchis mascula* (Young et al., 1998).

Aloe vera, which is known as Ghritkumari in Ayurveda is a very important plant rich in acetylated glucomannans. This is one of the most commercially popular plant of present times and in terms of major biological claims associated with this plant many of them seem to be concurrent with the presence of acetylated mannans (Lee et al., 2001; Reynolds & Dweck, 1999; Thomas, Goode, LaMaster, & Tennyson, 1998).

The structural attributes of mannans from *Aloe* spp. include organization of the two sugar units along the chain with homologous blocks of mannans along the chain. Various functionalities for the mannans of *A. vera* include their complement fixing ability *in vitro*, *in vivo* activation of macrophages and the adjuvant activity for treatment of viral and tumoral diseases (Jettanacheawchankit, Sasithanasate, Sangvanich, Banlunara, & Thunyakitpisal, 2009; Rodriguez Rodriguez, Darias Martin, & Diaz Romero, 2010; Simoes et al., 2009).

An acetylated 1 → 4 mannan chain also known as Acemannan has been found to be one of the most effective polysaccharide units for the mannans of *A. vera*. Acemannans have high water solubility and are considered to be active topically. These kinds of mannan from *A. vera* juice are supposed to have potent wound healing and anti-inflammatory properties (Lee et al., 2001; Reynolds & Dweck, 1999; Talmadge et al., 2004; Womble & Helderman, 1988; Zhang & Tizard, 1996).

Acemannan therapy appears to be advantageous in antiviral therapy as well, there are numerous reports indicating the use of acemannan therapy for the treatment of human immune virus (HIV) positive patients as was revealed in a complementary and alternative medicine therapy survey carried out in the United States. It would although be worth mentioning that any concrete usefulness of such a therapy still needs to be validated (Poor, Hall, & Poor, 2002; Stuart et al., 1997). It is important in our opinion to validate the molecular mechanism validating the role of ace-mannans in therapeutic application such as its use in HIV treatment. Without such information and further assessment no claims can be justified.

Acemannans from *A. vera* possess multiple activities that may have beneficial effects for gastrointestinal disease, including anti-inflammatory, analgesic and pro-healing effects. Acemannan from *A. vera* accelerates healing and reduce pain in aphthous stomatitis, and prevent stress-induced gastric ulceration in rat, stimulate collagen synthesis and fibroblast activity. In our view, the popularity of *A. vera* still needs to be thoroughly validated and with the number of ongoing clinical trials in this direction, a complete overview of role of acemannans on various health related benefits would be clearly elucidated (Eshun & He, 2004; Jettanacheawchankit et al., 2009; Rodriguez Rodriguez et al., 2010).

Acemannan from *Dactylorhiza hatagirea* has been shown to prevent testicular damage caused by heat in male rats. Growing evidence indicate that mannans have a potential role in providing a better health and acemannans are found to be useful in ameliorating diabetes as well as hyperlipidemic conditions, thus it is worth mentioning that further characterization of various Rasayan plants may provide a better evidence towards the role of different mannan containing drugs and their physiological well-being (Thakur, Loeppert, Praznik, & Dixit, 2008).

3.1.4. Xylans

Xylans and xylo-oligosaccharides (XOS) have become a mainstay in the nutritional products for human as well as veterinary usage. From the perspective of dietary supplement it is worth stating that the concept of Rasayana seems to be a traditional counterpart to modern day nutraceuticals and dietary supplements (Akpinar, Erdogan, & Bostanci, 2009).

Phylanthus niruri Linn. is an important medicinal plant belonging to the category of Rasayana and is known as Bhumi Amla in vernacular. In various studies conducted on the xylans isolated from *P. niruri* the immunomodulatory and hepatoprotective activity have been reported. Linear as well as complex acidic heteroxylans have been isolated from *P. niruri* which have been tested for their biological activity (Mellinger, Carbonero, Cipriani, Gorin, & Iacomini, 2005). It appears that the validation of biological activity of *P. niruri* xylans needs further evaluation before any significant attributes can be ascribed. It is well documented that the aqueous extract rich in heteroxylans possessed immunomodulatory and anti-tussive property. An aqueous extract of *P. niruri* rich in polysaccharide was also helpful in stimulating macrophage from mouse peritoneal cavity to produce superoxide O_2^- (Dirjomuljono, Kristyono, Tjandrawinata, & Nofiarny, 2008). It would also be worthwhile to carry out a standardization of the aqueous extract from *P. niruri* and quantification of heteroxylans in the aqueous extract, would help in assessing the immunomodulatory effects better.

Phyllanthus emblica Linn. is a very important medicinal plant in the Ayurvedic system of medicine and is commonly known as Amla. It is a constituent of numerous Ayurvedic formulation, the most popular one being Chyawanprash, and triphala churna (a combination of three potent Rasayana herbs). Chyawanprash is a

combination of nearly 54 herbs, Amla is the predominant plant in the formulation and is a rich source of antioxidant potential owing to its high vitamin C content (Krishnaveni & Mirunalini, 2010). The fruits of *P. emblica* are rich in nearly 30% polysaccharides and these polysaccharides have been considered to be a major source of antitussive and antiviral activities attributed to this plant (Ishtiaq, Hanif, Khan, Ashraf, & Butt, 2007; Nosal'ova, Mokry, & Hassan, 2003). In our view, there has been a lot of research on the non-polysaccharide components of the plant and the important polysaccharide contribution to the medicinal benefits have been partly overlooked, a further insightful exploration on the polysaccharides of *P. emblica* would surely lead to new lead compounds with potential health and dietary benefits.

Amalaki also known as Amla in Ayurveda (*P. emblica*) is one of the most superior Rasayanas and is also defined as acharya Rasayana or the lead Rasayana. It is considered to be a potent geriatric tonic and known to promote youthfulness in case of general debility. The polysaccharides from the plant also appear to have cyto-protectant activity as well as effectiveness against radiation-induced damage (Krishnaveni & Mirunalini, 2010).

In general, xylo-oligosaccharides or XOs exert their beneficial effect mainly by proper modulation of the gastrointestinal flora. Results obtained *in vivo* using rats proved that the administration of XO resulted in increased amounts of *Bifidobacterium* spp. in the gastrointestinal tract, and in increased total short-chain fatty acids in the rat cecum (Cloetens et al., 2010; Gullon et al., 2008). Tests carried out in humans proved that XOs are carbon sources for beneficial bacteria. For example, ingested xylobiose is not excreted in feces or urine in the 24 h following oral administration. Since xylobiose cannot be hydrolyzed either by saliva, pancreatin, gastric juice or intestinal mucosa homogenate, this fact suggests its utilization by intestinal bacteria (Cloetens et al., 2010; Grootaert, Verstraete, & Van de Wiele, 2006; Gullon et al., 2008). The metabolism of XOs is well understood in rodent models but their utilization in human beings is not fully determined. While information on colon fermentation of fructans and fructoligosaccharides is studied, xylans and XOs remain lesser understood in terms of their metabolic profiling. Experiments on simulated human intestine tract for understanding its metabolic utilization can provide vital information for their biological utilization.

3.1.5. Arabinogalactans

The interest in plant arabinogalactans for their biological activity began with the isolation of first arabinogalactan to be reported from the roots of *Angelica acutiloba* by Yamada, Kiyohara, Cyong, and Otsuka (1985). This was called (AGIIa) and was shown to activate the complement system.

In general there have been two basic classes of arabinogalactans identified, While type I has a $1 \rightarrow 4$ linked galactose moiety, the linkage is either $1 \rightarrow 3$ or $1 \rightarrow 6$ in type II. Type II arabinogalactans have been shown to possess major biological activities in most of the biological studies reported so far (Ricardo, Frederick, Frederick, & Reilly, 1985; van Holst & Clarke, 1985).

Piper nigrum is another important Ayurvedic plant that has been reported for numerous biological properties including adaptogenic and immuno modulatory potential. In a study primarily focused on the immuno-polysaccharides of *P. nigrum* the fractions of polysaccharides were isolated, clarified and appropriately freed from proteins using open column chromatography and enzymes. The resultant anti-complimentary polysaccharides PNIa and PNIIb were tested for their immunomodulator potential and the results provided evidence towards the utilization of these polysaccharides as a supplement for immune enhancement (Chun et al., 2002).

A few arabinogalactans from medicinal plants have also been shown to enhance the TNF release from macrophages (*Arnica montana*, *Plantago major*) (Deters, Lengsfeld, & Hensel, 2005).

So far in this review, we discussed the effect of individual polysaccharide components on various facets of health related potential and cited a few classical examples from the Ayurvedic plants. Since, Rasayana is a holistic concept which focuses on overall improvement of health, and because there is an overlap of the various carbohydrate components present in the plants, it is worthwhile to throw some light on the general aspects of biological function and the role various polysaccharides present in Rasayana plants as a contributor to these effects.

4. Carbohydrate polymers in Ayurvedic plants as immunomodulating agents

Possession of a strong immune system, defined in Ayurveda as 'Rog Nirodahak Kshamta' i.e. the ability to counteract diseases has been the guiding principle of Rasayana therapy (Grover, Vats, Rathi, & Dawar, 2001; Ven Murthy et al., 2010).

In studies investigating the effects of plant polysaccharides on macrophage responses, the predominant finding is that polysaccharides derived from higher plants activate macrophages. In reports by Schepetkin and Quinn (Schepetkin, Faulkner, Nelson-Overton, Wiley, & Quinn, 2005; Schepetkin & Quinn, 2006), polysaccharides derived from 35 plant species amongst 22 different families have been shown to enhance macrophage function. They activated or increased macrophage cytotoxic activity especially against tumor cells and microorganisms as well. This has been validated in various plants belonging to Rasayana category as well, a few classical examples include *A. racemosus*, *P. nigrum*, *A. pyrethrum*, to name a few.

Other effective properties of polysaccharides from Rasayana plants include their role in the positive modulation of factors, such as tumor necrosis factor (TNF-α), interleukin (IL)-1h, IL-6, IL-8, IL-12, IFN-γ and IFN-h2.

Polysaccharides do possess a counter-balancing role in terms of macrophage activity. This has been illustrated by Popov et al., in case of *Silene vulgaris* (Popov, Popova, Ovodova, Bushneva, & Ovodov, 1999). The concept of Rasayana roots itself into a balance of physiological homeostasis. Evaluation of counterbalancing effects as described in case of *Withania somnifera* can provide basis for the role of polysaccharides as Rasayan component in Ayurvedic herbs. This could be a future direction for the evaluation of herbs belonging to this specific class in Ayurveda.

Most of the Rasayana drugs investigated so far have shown immunomodulatory activity and are found to be immunoprotectants, thereby providing resistance against diseases and pathogens. Polysaccharides of *Astercantha longifolia*, *A. pyrethrum*, *Asparagus officinalis*, *Cassia senna*, *A. vera*, *C. borivilianum*, *Chlorophytum arundinaceum*, *A. racemosus* and many other Rasayana herbs defined in Ayurvedic literature have been worked out for their immunomodulatory activity. Primarily, all the drugs are helpful for improving the overall resistance of the body against pathogenic interventions (Ali, 1998; Chakrabarty, Datta, Ghosh, & Debnath, 2001; Chauhan et al., 2010; Govindarajan et al., 2005; Sharma et al., 2010; Thakur, Bhargava, & Dixit, 2007).

Prevention of immune-suppression induced by drugs or resulting from exposure to gamma radiation is another important facet that has been validated as a result of administration of polysaccharide rich aqueous extract of Ayurvedic herbs.

It has been a desirable attribute to have immunomodulating agents that are possibly free from side effects and can be administered for long duration, if possible throughout life, to obtain a continuous immune activation. This is highly desirable for the prevention of diseases and overall health benefits of the society. Interest in immunomodulators for use in cancer therapy has led to the discovery of a variety of chemically defined compounds, plant

and microbial products, etc. having immunomodulatory activity. However, the clinical value of most of the immunotherapeutic regimens tested so far has not been proven unequivocally (Murphy, 2010).

Rasayanas as immunomodulating agents hold a prominent ability to activate the immune system without causing a major alteration in the normal physiological functioning. As an example, in a report published by Vayalil et al. it was observed that the Rasayana treatment in animals improved peripheral leukocyte count as well as absolute number of polymorphonuclear cells (Vayalil, Kuttan, & Kuttan, 2002b). This enhancement was only observed up to a standard upper limit for normal blood, and the other hematological parameters remain unchanged. Such observations clearly validate the potential value of Rasayanas in balancing the overall physiological functionality. Unlike cytokines or other immunomodulators, this enhancement did not exceed the normal range of respective cells in the peripheral blood. The maximum counts were observed six days after the initiation of the drug treatment. These observations on animals have been further validated under clinical trials as reported by Vayalil et al. (Vayalil, Kuttan, & Kuttan, 2002a). Exact role of individual herbal drug component may require a longer time before validation and contribution of polysaccharides would be invaluable in this context. While modern therapeutics focuses on protein and peptide as leads for novel compounds, it can be foreseen that polysaccharides would also serve a lucrative lead for immunotherapeutics.

A proteoglycan from *Crocus sativus* Linn. also known as Saffron was evaluated for its immunomodulatory and anti-invasive properties. Non-cytotoxic concentrations of this glycoconjugate promoted significant macrophage activation, detected by the release of nitric oxide. A rapid activation of protein kinase C and NF-κB was obtained after proteoglycan treatment explaining the production of nitric oxide synthase. Proteoglycan concentrations ranging from 10 to 1000 ng/ml specifically promoted apoptosis of macrophages, probably triggered by their activation (Escribano et al., 1999a, 1999b, 2000).

5. Polysaccharides as antioxidants

The ability to counteract the damaging effects of the reactive oxygen species (ROS's) is one of the major attributes of herbal drugs to treat various degenerative disorders and has been excellently reviewed by Govindarajan et al. (2005). Although, the major contributors of antioxidant effectiveness are polyphenolic compounds, flavonoids, etc., but in recent past there has been an elucidation of possible role of plant polysaccharides possessing antioxidant activity for stabilization of cellular membranes as well as prevention of degenerative mechanisms operative in the biological milieu. A number of polysaccharides from plant sources have been evaluated in the recent past for their antioxidant potential. We will throw a brief light on some of the Rasayana herbs evaluated from this perspective. Kamat et al., performed studies on *A. racemosus* against γ radiation induced microsomal damage and *in vitro* antioxidant activity. According to their study the polysaccharide rich fraction of *A. racemosus* which mainly contains short chain oligofructose was as effective as the positive standards ascorbic acid in preventing microsomal damage (Kamat, Boloor, Devasagayam, & Venkatachalam, 2000). Kardosova and Machova screened the polysaccharides from 11 plants used in herbal medicine for their *in vitro* antioxidant activity. The polysaccharides were investigated for their ability to inhibit peroxidation of soybean lecithin liposomes by OH radicals. The highest inhibition was found with glucuronoxylans of *A. officinalis* var. *robusta* and *P. lanceolata* var. *libor*, aerial parts (Kardosova and Machova, 2006). Sreevidya, Srinivasa Rao, Sullia, Ladha, and Reddy (2006) evaluated the polysaccharides of *C. borivilianum* against oxidative stress and found that the polysaccharide rich fraction (mainly fructans and acetylated mannans) was most effective and could reduce oxidative stress as well as reverse the oxidative damage as well. The aqueous extract of the plants *C. borivilianum*, *A. racemosus, D. hatagirea, O. latifolia* and *C. orchioides,* could ameliorate testicular damage and the authors attributed the effectiveness in part to the antioxidant potential of polysaccharides from these plants providing a resistance to the free radicals generated subsequently after the release of heat shock proteins from the testicular germ cells (Thakur et al., 2008).

6. Ayurvedic plant polysaccharides evaluated for biological activities

In Chinese system of medicine the tea conjugate polysaccharides have been considered to be highly beneficial in balancing the damage caused by reactive oxygen species (ROS). The free radical scavenging effects were validated by lipid peroxidation assay as well as in alloxan induced hyperglycemia (Shim et al., 2010). Since, many Ayurvedic preparations belonging to the category of Rasayana have been linked with the usage of tea, henceforth, it can be inferred that the polysaccharides of tea or such herbal preparations in the form of tea could be a major contributor to various activities including immunological, anti-radiation, anti-blood coagulation, anti-cancer, anti-HIV and hypoglycemic activities (Zhou, Ding, Wang, & Xie, 1997).

Subramanian, Chintalwar, and Chattopadhyay (2002) studied the antioxidant activity of an arabinogalactan polysaccharide (TSP) isolated from *T. cordifolia* which belongs to the category of Rasayana plants in Ayurveda. The polysaccharide showed good protection against iron-mediated lipid peroxidation of rat brain homogenate as revealed by the thiobarbituric acid reactive substances (TBARS) and lipid hydroperoxide (LOOH) assays. TSP also provided significant protection to protein against X-ray induced damage. The protective action can possibly be explained by its very high reactivity towards diphenylpicrylhydrazyl (DPPH), superoxide radicals and the most damaging of radicals, the hydroxyl radical.

Since, membrane stabilization as well as prevention of cellular damage via antioxidant mechanism is an important contributor to the general concept of well-being, hence polysaccharides appear to be prominently effective via the antioxidant mechanism for eliciting a balancing action in the body.

7. Polysaccharides as anti-tumor agents

The concept of Rasayana deals with the prevention of any disorders and strengthening of the overall immune system to the extent that any physiological disturbances including the formation of tumor are counteracted appropriately via the NK cell and macrophage activation. Although, there has been ample evidence collected so far elucidating the role of various polysaccharides isolated from Ayurvedic plants in preventing or counteracting the tumor growth (Thakur et al., 2010).

A few polysaccharides from such herbs have been found to be effective in reducing the incidences of hepatocellular carcinoma (HCC). With a median survival of 8 months past the inception of HCC there are very few treatments available. As alternative or complementary therapy, Ayurveda, the most ancient traditional system of Indian medicine has been emerging with scientific advancements in the treatment of cancer. Rapidly growing knowledge of anti-cancer Ayurvedic herbs in basic science appears at biochemical and molecular level (Balachandran & Govindrajan, 2005). A few Ayurvedic herbs and their polysaccharide components which have been considered to play a vital role include

Andrographis paniculata, *Semecarpus anacardium*, *Trichopus zeylanicus*, *Aegle marmelos*, *P. niruri*, *Phyllanthus amarus*, *Sphaerenths indicus*, *Piper longum* (Chopra, 2000; Du et al., 2006; Gautam et al., 2009; Grover et al., 2001; Jagetia & Baliga, 2004; Jagetia et al., 2004; Narasimhan et al., 2006; Rege et al., 1999; Scartezzini & Speroni, 2000; Thakur et al., 2007; van de Wiele et al., 2007; Vats, Yadav, & Grover, 2004; Wagner, 1999). Most of these Rasayana herbs exert a direct hepatoprotective activity and have been found to be very useful in prevention or cure of hepatocarcinoma in animal models. The major active compounds from these herbs are distinct but in most cases the polysaccharides appear to provide an adjuvant effect in prevention and cure of tumor. The aqueous extract from these herbs seem to have a complimentary effect in prevention of hepatocarcinomas.

Another interesting result for the potential anti-tumor lectins has been reported in *Acorus* species known as Bach in vernacular. *Acorus calamus* Linn. (ACL) and *Acorus gramineus* Solandin Ait. (ACG) *Acorus* lectins readily agglutinated rabbit, rat and guinea pig erythrocytes. Both ACL and AGL also reacted with RBCs from sheep, goat and human ABO blood groups after neuraminidase treatment. ACL and AGL were inhibited by mannose/glucose and their derivatives. These lectins showed potent mitogenic activity towards mouse splenocytes and human lymphocytes. Both ACL and AGL also significantly inhibited the growth of J774, a murine macrophage cancer cell-line and to lesser extent WEHI-279, a B-cell lymphoma. (Bains et al., 2005; Mehrotra et al., 2003).

It is unequivocally stated that polysaccharides possess potential as tumor preventive and antitumor properties, the major lacuna in most of the research carried out so far appears to be the lack of clinical and molecular understanding. It is also important that a polysaccharide from similar plant source be tested on different tumor and non-tumor cell lines to evaluate the specificity of the lead compound.

8. Polysaccharides and fertility

Amongst various attributes of Rasayana herbs, the *Vajikaran* effect i.e. the ability to boost sexual performance is an interesting attribute, which has been a subject of scientific curiosity in the recent past (Thakur, Chauhan, et al., 2009). With the ever increasing concerns for infertility, the role of herbal drugs in improving reproductive function and prevention of sexual dysfunction has become important. Polysaccharides from Ayurvedic Rasayana herbs have shown potential for prevention of physical damages to reproductive function. Five Rasayana herbs (*A. racemosus*, *C. borivilianum*, *D. hatagirea*, *C. orchioides* and *O. latifolia*) were able to significantly ameliorate the sexual dysfunction as a result of heat induced testicular damage (Thakur et al., 2008, 2010). The polysaccharides rich extracts were also found to be effective in *in vitro* preservation of sperm count (Thakur & Dixit, 2007). Apart from this the polysaccharides may also affect the seminal fructose content, since fructolysis is an important step for providing the motility to spermatozoa and their ability to traverse zona pellucida, hence there is a probability of the role of polysaccharides in improving trans-pellucida penetration. This has been illustrated in the case of Boar spermatozoa, where the monosaccharide treatment significantly reduced the penetration activity and acrosome reaction, whereas the activity was significantly improved in the presence of polysaccharides, especially mannans and glucans (Park, Hwang, Cheong, Yang, & Kim, 2002). It therefore provides an indication that the polysaccharides play a major role in improving fertility and the presence of mannans, fructans and glucans in most Vajikarana Rasayana herbs provide a basis for their folkloric benefits in improving reproductive functionality.

9. Some Rasayana herbs and their polysaccharides

Further on, we would discuss some of the important Ayurvedic Rasayana herbs for which the polysaccharides have already been established as a major contributor to their biological activity.

9.1. *Anacyclus. spp.*

A. pyrethrum also known as Akarkara in Ayurvedic system of medicine and pellitory in western medicine is a very important Ayurvedic Rasayan drug. Although, it is not native to most part of India and is generally imported but it finds use in many Ayurvedic formulations (Puri, 2003a). The plant contains a high amount of hot water soluble polysaccharides which was found to be mainly Inulin type fructans (Sharma et al., 2010). Bendjeddou et al. reported the immunostimulating activity of hot water soluble polysaccharide extract of *A. pyrethrum* and showed a marked stimulating effect on the reticulo-endothelial system (RES) and increased the number of peritoneal exudate cells (PEC), and spleen cells of mice at a dose of 50 mg/kg body weight. The polysaccharide extracts of *A. pyrethrum* markedly enhanced the proliferation of the murine spleen cells *in vitro* (Bendjeddou, Lalaoui, & Satta, 2003). Tewfik et al. have further reported a refined working protocol for the isolation and identification of bioactive compounds from aqueous extract of *A. pyrethrum* (Tewfik, 2007).

9.2. *Asparagus spp.*

A. officinalis and *A. racemosus* Willd. are very important Rasayana herb of Indian system of medicine. The plant is also known as Shatavari and is a part of most of the Ayurvedic Rasayana preparation including Chyawanprash an outstanding adaptogenic preparation (Ali, 1998; Bopana & Saxena, 2007; Gautam et al., 2009). The plant is rich in fructo oligosaccharides and contains neokestose type ($2\rightarrow1$, $2\rightarrow6$) fructopyranosyl linked units of fructans (Yamamori, Onodera, Kikuchi, & Shiomi, 2002). The polysaccharide rich fraction of *A. racemosus* was evaluated for antioxidant activity and liver microsomal protection against gamma irradiation (40 mv) by Kamat et al. (2000). The possible antioxidant effects of crude extract and a purified aqueous fraction of *A. racemosus* against membrane damage induced by the free radicals generated during gamma-radiation were examined in rat liver mitochondria. Gamma-radiation, in the dose range of 75–900 Gy, induced lipid peroxidation as assessed by the formation of thiobarbituric acid reactive substances (TBARS) and lipid hydroperoxides (LOOH). The effective dose of 450 Gy, antioxidant effects of *A. racemosus* extract were studied against oxidative damage in terms of protection against lipid peroxidation, protein oxidation, depletion of protein thiols and the levels of the antioxidant enzyme, superoxide dismutase. An active fraction consisting of polysaccharides (termed as P3) was effective even at a low concentration of 10 μg/ml. Both the crude extract and the P3 fraction significantly inhibited lipid peroxidation and protein oxidation. The antioxidant effect of P3 fraction was more pronounced against lipid peroxidation, as assessed by TBARS formation, while that of the crude extract was more effective in inhibiting protein oxidation. Both the crude extract and the P3 fraction also partly protects against radiation-induced loss of protein thiols and inactivation of superoxide dismutase. The inhibitory effects of these active principles, at the concentration of 10 μg/ml, are comparable to that of the established antioxidants glutathione and ascorbic acid. The results therefore indicated that the extracts from *A. racemosus* have potent antioxidant properties *in vitro* in mitochondrial membranes of rat liver (Kamat et al., 2000). The polysaccharide rich fraction of *A. racemosus* has been proven to be a potent anti-ulcer agent. Rege et al. reviewed potent adaptogenic activity evaluated against

Table 1
List of some Ayurvedic Rasayana plants with characterized polysaccharides and their immunomodulatory activity.

Plant name	Common name	Polysaccharide/water soluble carbohydrates studied	Reported properties evaluated for the herb
Acorus calamus (Rhizomes)	Bach/Vach	Rich in lectins, and pectic polysaccharides with up to 85% D-galacturonic acid	Ethyl acetate extract showed potent antioxidant activity by inhibition of 1,1-diphenyl-2-picrylhydrazyl (DPPH) free radical DPPH scavenging activity at three different concentrations (0.2, 0.1 and 0.01 g/ml) showed a maximum activity of 86.43% at 0.2 g/ml. Activates macrophage and elicits Th1 response Lectins exhibited mitogenic and tumor inhibitory activity in murine macrophage cell line and B cell lymphoma
Aloe vera Linn. expressed juice as well as leaf exaudate	Gwarpatha/Aloe	Mainly rich in acetylated glucomannans	As an ointment useful against numerous skin diseases, burns and inflammation, etc. Effective against functional sterility and disturbed menstrual function Polysaccharide fraction rich in mannans was found to be effective against stressors and showed prominent antioxidant properties *in vivo* as well as *in vitro*
Andrographis paniculata (leaves)	Kalmegh		Decreased kidney TBARS level in normal rats along with increase in the activity of SOD and CAT, but had no significant effect on GSH-px activity in diabetic rats showing that it possesses an anti-hyperglycemic property, and may also reduce oxidative stress in diabetic rats Protective effect in the activity of SOD, CAT, GSH-PX, GSH-R as well the level of GSH with decreased activity of lipid peroxidase proving it has antioxidant activity which is corroborative to its potent anti-hepatotoxic activity
Anacyclus pyrethrum (roots)	Akarkara	Inulin type fructans with $2 \rightarrow 1$ linkage (mainly inulin type)	Hot water soluble polysaccharides stimulated the reticuloendothelial system (RES) and increased the number of peritoneal exudate cells (PEC), and spleen cells of mice
Asparagus racemosus (roots)	Shatavari	Oligo-fructans with mainly neokestose type fructans (having $2 \rightarrow 1$ and $2 \rightarrow 6$ type linkage)	*Asparagus racemosus* against membrane damage induced by the free radicals generated during γ-radiation were examined in rat liver mitochondria *A. racemosus* extract were studied against oxidative damage in terms of protection against lipid peroxidation, protein oxidation, depletion of protein thiols and the levels of the antioxidant enzyme, superoxide dismutase. An active fraction consisting of polysaccharides (termed as P3) was effective even at a low concentration of 10 μg/ml. Both the crude extract and a fraction significantly inhibited lipid peroxidation and protein oxidation. A potent antioxidant properties *in vitro* shown in mitochondrial membranes of rat liver. *In vitro* antioxidant activity of isolated fractions was evaluated
Calotropis procera (latex)	Aak		Resulted in an increase in the hepatic levels of the endogenous antioxidants, namely superoxide dismutase (SOD), catalase and glutathione. Brought down the levels of thiobarbituric acid-reactive substances (TBARS) in alloxan-induced diabetic rats
Punica granatum Linn. (fruit)	Anar	Complex polysaccharide fraction from pericarp	Inhibits 1,1-diphenyl-2-picrylhydrazyl (DPPH) and 2,2′-Azinobis[3-ethylbenzothiazoline-6-sulfonate] $ABTS^{+}$ Anti-glycation activity and inhibition of the formation of fructosamine in the BSA/Glucose system Inhibition of mushroom tyrosinase and tumor inhibitory properties
Saccharum officinarium Linn.	Ganna	Non sucrose polysaccharide fraction Saccharin A-F	Potent hypoglycemic activity by Saccharin B and E
Eclipta alba Linn. (leaves)	Bhringaraj	Arabino-galactan and Mannan	Polysaccharide extract (EPA) possessed significant hypoglycemic activity
Gmelina arborea Roxb.	Gambhari	Lignins and galactans	Radical scavenging activity and hypoglycemic effects
Solanum nigrum Linn. (seeds)	Makoya	Crude polysaccharides	Tumor growth inhibition in cervical cancer U14. Administration of polysaccharides increased expression of Bax while of Bcl-2 and mutant p53 decreased
Feronia limonia Linn. (latex)	Kaitha	Pectic polysaccharide (partially carboxymethylated polygalacturoan)	Significant *in vivo* inhibition of Ehrlich ascites carcinoma cell growth inhibition Increase in number of peritoneal exudate macrophages Anti-microbial activity
Hordeum vulgare (fruits)	Java	$1 \rightarrow 3$, $1 \rightarrow 4$ β-D-glucans	Immunomodulating activity, Carcinostatic properties and effectiveness against HIV viruses
Mucuna pruriens Linn.	Kiwanch	Starch	Food products, jellies, etc. have been promoted as functional food. Improvement of semen quality
Tinospora cordifolia Linn.	Glioya	Arabinogalactan	Protection against iron-mediated lipid peroxidation of rat brain homogenate as Protection to protein against gamma-ray induced damage
Myristica fragrans Linn. (fruit)	Jayphal	Pectic polysaccharides	Aqueous extract was tested for Insulin like biological activity in rat epididyal adipocyte assay and showed potent activity via cellular glucose metabolism pathway

Table 1 (*Continued*)

Plant name	Common name	Polysaccharide/water soluble carbohydrates studied	Reported properties evaluated for the herb
Ocimum basilicum Linn.	Tulsi	Mucilages, 1 → 4 linked xylans, β-glucans	Modulation of immune response Mucilagenous extract of seeds was useful in binding to chromium and also useful in treatment of aluminum toxicity Antioxidant and radical scavenging activity Gastroprotective effect of the crude polysaccharide fraction and prevention of ulcer formation
Croccus sativus Linn. Stigma	Kesar	Proteoglycans	HeLa cells exposed to this glycoconjugate showed swelling and local plasma membrane evaginations, suggesting that cytotoxicity is mediated by extracellular fluid uptake
Angelica sinensis Linn.	Danggui	Total polysaccharide	Gastroprotective effects against ethanol and indomethacin induced gastric ulcerations via inhibitory action on neutrophil infiltration in the gastrointestinal mucosa. Protective effect against immunological damage to colon Polysaccharide rich extract was effective in the protection of liver damage induced by acetaminophen, which is associated with the glutathione depletion and nitric oxide synthase activation in the liver
Nigella sativa Linn.	Kalaunji	Pectic polysaccharides	Inhibition of galectin-3 mediated cellular interactions was validated in MDA-MB231 cell lines. It inhibited the hemagglutination at a concentration of 130 μg/ml
Chlorophytum tuberosum Baker.	Musli	Inulin type fructans with 2 → 1 linkage	Polysaccharide rich extract was found to possess potent immunomodulatory activity with IC_{50} values being 225.31, 888.44, 809.22 and 422.97 μg/ml for scavenging of DPPH, nitric oxide, lipid peroxidation and ferry bi-pyridyl complex, respectively, along with a integral antioxidant activity of 2.986 nmol ascorbic acid/g equivalents in photochemiluminescence assay
Nelumbo nucifera Linn.	Kamal kand	Complex polysaccharide with mainly galactomannans	Although no direct study on isolated polysaccharides have been reported, yet in case of most of the studies on aqueous extract the polysaccharide rich fraction modulated the enhancement of immune function

various stressors and pharmacological screens for the whole aqueous extract of *A. racemosus* which is rich in fructo-oligosaccharides and fructans (Rege et al., 1999). Aqueous extract of *A. racemosus* also showed potent immunostimulatory activity which can in part be contributed to the polysaccharides present in abundance in the aqueous extract of the herb, this could also contribute to protection against cancer chemotherapy (Gautam et al., 2004, 2009). The fructo-oligosaccharide rich fraction was also evaluated for effect on sexual behavior, pendiculatory activity and preservation of *in vitro* sperm count by Thakur and Dixit (2007). The aqueous extract exhibited promising potential and also validated the designation of this herb as 'Vajikaran Rasayan' (herbs used for improving sexual functions).

9.3. *Chlorophytum spp.*

Plants from the *Chlorophytum* species have been recently evaluated for their beneficial effect on immune system, reproductive activity and hypolipidemic activity. The major active fraction has been the aqueous extract which is composed of 70–75% of polysaccharides, mainly 2 → 1 linked inulin type fructans and ace mannans (Sreevidya et al., 2006; Thakur, 2008). The polysaccharide from the plant has also exhibited amelioration of sexual dysfunction and oxidative stress in hyperglycemic male rats. While direct contribution of polysaccharides in improving the sexual behavior is not yet defined, it was clear that the polysaccharide rich extract of *C. borivilianum* was highly beneficial in *in vitro* preservation of sperm count and motility. The presence of both fructan and mannan in *C. borivilianum* also provides an interesting attribute for further evaluation of physiological processes in the plant triggering two separate polysaccharide production (Thakur, 2008).

A list of different Rasayana plants exhibiting different biological activities has been detailed in Table 1.

10. Conclusions

Polysaccharides from different medicinal plants exhibit biological activities that can be of importance for mankind in the future. The most interesting amongst these includes the effects on immune system which may lead to the production of better medicines to be used as supplements in cancer treatment. The use of these polymers will stimulate the immune system and the possibility for a lower dose of the existing treatment is obvious. Polysaccharides can also be used in relatively large doses and no side effects have been observed so far. But other interesting effects have also been seen like those on different viruses, in relation to diabetes, ageing problems, etc. There appears to be a low degree of structural similarity between the different types of substances so far being the object for structure-activity studies, but looking more closely into the overall structure of some of these, there may be certain important common structural features. Therefore, it can be concluded that a systematic evaluation of the polysaccharides from a biological perspective does hold potential for future leads in therapeutic drug development. Also, the concept of Rasayana and the role of Rasayana polysaccharides provide an interesting symphony for the concept of well-being and disease prevention in an ethnopharmacological perspective.

Conflict of interest

Authors would like to declare no conflicts of interest.

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