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Isolation, Chemical Structure Elucidation and Bioactivities of *Argania spinosa* Cell Wall Polysaccharides: A Review

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ABSTRACT
The polysaccharides obtained from *A. spinosa* benefit from promising prospects in a number of different directions, thanks to their huge structural heterogeneity, reflected by the large number of diverse uses as the food, pharmaceutical, cosmetics, paper and textile industries, as well as water depollution, catalysis, membranes and others. This paper reviews the methods of separation, purification, structural elucidation and valorization in different fields of *A. spinosa* cell wall polysaccharides. This review is a useful synthesis for further research and improvement of various properties of *A. spinosa* cell wall polysaccharides.

Keywords : Argan tree, polysaccharide, extraction, structural characterization, valorization.

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INTRODUCTION

Polysaccharides constitute a class of natural products which is characterized by a large variety of structures and physicochemical properties that justify their diverse uses in food, pharmaceutical, cosmetic, paper industries, as well as in oil extraction[1]. More recently, the study of polysaccharides as bioactive agents has gained increased interest, favored by their biocompatibility, biodegradability and their absence of toxicity[2,3]. The isolation, purification and use of polysaccharides depend on their structural characteristics but also on the biological matrices in which they are naturally present. Structural analysis can provide valuable information for the understanding of the biological functions of polysaccharides, but the diversity and the aperiodic arrangement of the chains make it difficult to uncover the links between structure and function[4,5].

The Algerian Sahara has a diffuse and sparse vegetation[6]. Some species have bioactive properties that make them of interest in various fields[7]. One of these species, the Argan tree -*Argania spinosa* (L.) Skeels (synonyms *Argania sideroxylon* Roem. & Schult., *Sideroxylon spinosum* L.) - is, in Algeria and Morocco, the only representative of the tropical family Sapotaceae, which otherwise includes nearly 600 species[8,9]. It is a very hard wood tree, which is recognizable with a short and tormented trunk topped by a very large crown; its life expectancy lies between 150 - 200 years. The Argan tree is perfectly adapted to the arid saharan bioclimatic context thanks to the mechanisms that regulate the simultaneous variations of foliar water potential and transpiration[10]. Owing to its strong and deep root system, this species ensures the ecological balance of its habitat, protecting the soil from both water and wind erosion[11].

To the best of our knowledge, either the extraction and purification methods or the structural characteristics of the polysaccharides of *A. spinosa* have not been reviewed yet. Therefore, in order to better understand these macromolecules, this review seemed appropriate, the aim being to give an overview of the techniques used for the study of *A. spinosa* polysaccharides, and more especially their structure and their biological activities.

EXTRACTION, PURIFICATION AND CHARACTERIZATION METHODS OF *ARGANIA SPINOSA* POLYSACCHARIDES

Extraction of Argania spinosa polysaccharides

The main problem encountered by the experimenter is the chemical richness of the plant cell wall, which is reflected by a large structural diversity of macromolecules, essentially the polysaccharides. If the protocols to be used must be sufficiently selective to extract a precise category of macromolecules, they also must ensure that the molecular structures are subjected to the least possible damage[12,13]. A detailed review of the literature in the field of polysaccharide extraction indicates that there exist a large number of classical protocols for the extraction of the different groups of polysaccharides[14,15]. Hot water extraction of polysaccharides from the argan tree is the most widely used method for the isolation of high methyl pectins, pectic acids or their pectate salts,owing to their high affinity for water[16,17]. On the other hand, low-methyl pectins, which are present in the wall as calcium-pectin complexes, can be extracted with solutions of calcium-chelating agents such as EDTA[16,17,18] and CDTA[19]. These compounds lead to the formation of pectates which are easily dissolved in hot water together with pectins[20].

Hemicelluloses as a whole represent the largest polysaccharide fraction of argan, as in all dicots. They are usually extracted with increasing concentrations of alcalis[21]. In their native state, hemicelluloses are more or less extensively acetylated at the *O*-2 or *O*-3 positions and are intimately bound to other parietal polysaccharides by hydrogen bonds. Thus, during alkaline extractions, saponification of these acetyl ester functions, and the breaking of hydrogen bonds contribute to the

solubilisation of hemicelluloses[22]. Alkali concentrations used range from 0.17 to 6 M[18,23,24,25,19,26,27]. The general extraction procedures of *A. spinosa* polysaccharides are summarized in Table 1.

Table 1. Polysaccharides isolated from *A. spinosa*

Polysaccharides names	*Argania* organ	*Argania* origin	Chemical Isolation	Type of polysaccharide	References
AFRG-I and AFRG-II	Fruit pulp	Southern Morocco	0.05 M CDTA	Chelate-soluble pectin	Aboughe-Angone et al.[19]
AF1OH and AF4OH			1 M and 4 M KOH	Alkali-soluble hemicellulose	
P_1-H_2O	Pericarp fruit	Stidia region, west coast of northern Algeria	Distilled water at 100° C	Water soluble pectin	Hachem et al.[18]
P_2-EDTA			1% EDTA	Chelate-soluble pectin	
H_1-KOH 1M and H_2-KOH 4M			1 and 4 M KOH	Alkali-soluble hemicellulose	
ALT-WSP	Leaves	Tindouf region, Southwest Algeria	Distilled water at 100° C	Water-soluble pectin	Hachem et al.[17]
ALT-CSP			1% EDTA	Chelate-soluble pectin	
ALS-WSP	Leaves	Stidia region, west coast of northern Algeria	Distilled water at 100° C	Water-soluble pectin	Hachem et al.[16]
ALS-CSP			1% EDTA	Chelate-soluble pectin	
A1OH and A4OH	Leaves	Souss region, south of Morocco	1 and 4 M KOH	Alkali-soluble hemicellulose	Ray et al.[27]
B1OH and B4OH					
PWSF-I, PWSF-II and PWSF-III	Seed pericarp of fruit	Essaouira region, Morocco	0.5, 1, and 2 M NaOH	Water soluble hemicellulose	Habibi and Vignon[26]
PWIF-I, PWIF-II and PWIF-III				Water insoluble hemicellulose	
HX	Fruit pericarp	Ait Amira region, Morocco	4,3M KOH	Alkali-soluble hemicellulose	Barbat[25]
MGX A					
FI KOH and FIII KOH	Leaves	Tindouf region, Southwest Algeria	24% KOH	Alkali-soluble hemicellulose	Hachem et al.[23] ; Hachem et al.[24]
FI NaOH and FIII NaOH			4.3 M NaOH		

Purification and characterization methods

Argania spinosa polysaccharide purification methods used size-exclusion chromatography on DEAE-Trisacryl M, Sepharose CL-4B, Biogel P6 and Biogel P2, which are generally associated with other techniques, such as alcoholic precipitation followed by centrifugation[28], enzymatic[29] and or acid[30] treatment. As a result of these purifications, various polysaccharides were isolated, and their structural characteristics were further defined by the following methods: infrared (IR) spectroscopy, gas chromatography (GC), high performance anion exchange-pulse amperometric detection-chromatography (HPAE-PAD-chromatography), matrix-assisted laser desorption ionization-time of flight mass spectrometry (MALDI-TOF MS) and nuclear magnetic resonance (NMR), as shown in Table 2.

Table 2. Techniques used in the study of *A. spinosa* polysaccharides

Polysaccharide fraction	Separation and/or Purification methods	Hydrolysis method	Polysaccharide	Characterization methods	References
AFRG-I	Acidification (AcOH, pH 6)	Endopolygalacturonase	Rhamnogalacturonan-I	GC GC–MS MALDI-TOF	Aboughe-Angone et al.[19]
AFRG-II			Rhamnogalacturonan-II		
AF1OH and AF4OH	Precipitation (80% EtOH)/ Centrifugation	β -1,4-endoglucanase	Xyloglucans		
P_1-H_2O	Precipitation (EtOH)/ Centrifugation	2M TFA	Homogalacturonan Rhamnogalacturonan-I * Rhamnogalacturonan-II	GC FT-IR	Hachem et al.[18]
P_2-EDTA					
H_1-KOH 1M and H_2-KOH 4M	Acidification (20% AcOH)		Homoxylan Xyloglucans Arabinoglucuronoxylans		
ALT-WSP	DEAE-Trisacryl M column	2M TFA	Rhamnogalacturonan-I	GC GC–MS ^{13}C NMR	Hachem et al.[17]
ALT-CSP			Homogalacturonan Rhamnogalacturonan-I*		

ALS-WSP	DEAE-Trisacryl M column	2M TFA	Homogalacturonan, Rhamnogalacturonan-I*	GC GC–MS ^{1}H NMR ^{13}C NMR	Hachem et al.[16]
ALS-CSP			Homogalacturonan Rhamnogalacturonan-I*		
A1OH and A4OH	Sephadex G-15 column HPAE-PAD-chromatography	Endo-(1 → 4)-β-D – xylanase	Glucuronoxylan	GC GC–MS MALDI-TOF MS ^{1}H NMR	Ray et al.[27]
B1OH and B4OH		Endo-(1 → 4)-β-D - glucanase	Xyloglucans		
PWSF-I, PWSF-II and PWSF-III	Biogel P6 column	H_2SO_4	Glucuronoxylan	GLC ^{1}H NMR ^{13}C NMR	Habibi and Vignon[26]
PWIF-I, PWIF-II and PWIF-III			Homoxylan		
HX	Dowex 1×2 chloride form column Biogel P2	Autohydrolyse	Homoxylans	GC MALDI-TOF MS NMR ^{1}H	Barbat[25]
MGX A			Glucuronoxylans		
FI KOH and FIII KOH	Sepharose CL-4B column Biogel P2	Endo-β-(1→4)-xylanase	Arabinoglucuronoxylans	GLC FT-IR MALDI-TOF MS	Hachem et al.[24]
FI NaOH and FIII NaOH		2 M HCl	Glucuronoxylans Rhamnogalacturonans	GLC MALDI-TOF MS	Hachem et al.[23]

The five polysaccharide fractions of pectic nature (AFP, AL-WSP, AL-CSP, ALS-WSP and ALS-CSP) can be considered as models of the structure of pectins secreted into the cell walls of the argan tree. The fractions contents have similar structures and correspond to homogalacturonan, rhamnogalacturonan-I, rhamnogalacturonan-II with prevalence of rhamnogalacturonan-I[16,17,19].

The alkali-soluble fraction extracted showed that it is composed of a polysaccharide of hemicellulosic nature. Unsubstituted linear xylans (PWIF-I, PWIF-II and PWIF-III) [26], xylans (A1OH, A4OH, PWSF-I, PWSF-II, PWSF-III, FI KOH, FIII KOH, FI NaOH and FIII NaOH) substituted to a greater or lesser extent by 4-O-methylglucuronic acid [23,24,26,27] and xylogucans (XXGG, XXXG, XXLG, XLLG, XXFG, XLXG/XXLG, XLFG and XUFG) as is the case in the primary walls of dicotyledons[19,27].

Structural Features of the oligosaccharides generated

Detailed data on the monosaccharide compositions and chemical structures of the repeating units generated from the polysaccharides of *A. spinosa* are listed in Table 3.

Table 3. Structural Features of oligosaccharides generated from *A. spinosa* polysaccharides

Polysaccharide fractions	Monosaccharide composition	Repeating units	References
AFRG-I	Rha, Ara, Xyl, Glc, Gal, Gal A, Glc A, 2-*O*-Me-Fuc, 2-*O*-Me-Xyl in the ratios 12:60:1:1:21:3:3 [a]	nd	Aboughe-Angone et al.[19]
AFRG-II	Rha, Fuc, Ara, Xyl, Man, Glc, Gal, Gal A, Glc A, Api, 2-*O*-Me-Fuc, 2-*O*-Me-Xyl in the ratios 20:5:34:6:1:7:17:11:8:5:10:7 [a]	nd	
AF1OH	Fuc, Ara, Xyl, Man, Gal, Glc in the ratios 1:8:47:3:12:29 [a]	XXGG XXXG XXLG XLLG	
AF4OH	Fuc, Ara, Xyl, Man, Gal, Glc in the ratios 2:6:41:7:13:31 [a]		
P_1-H_2O	Rha, Ara, Xyl, Gal, Glc in the ratios 5:72:3:15:5 [b]	nd	Hachem et al.[18]
P_2-EDTA	Rha, Ara, Xyl, Gal, Glc in the ratios 6:75.5:1.5:10:7 [b]	nd	
H_1-KOH 1M	Rha, Fuc, Ara, Xyl, Gal, Glc in the ratios 4:4:18:53:9:14 [b]	nd	
H_2-KOH 4M	Rha, Fuc, Ara, Xyl, Gal, Glc in the ratios 4:2:11:47:7:29 [b]	nd	
ALT-WSP	Rha, Fuc, Ara, Xyl, Gal, Glc in the ratios 15.5: 0.5: 65: 2.5 :13.5: 3 [b]	→ [4)-α -D-GalpA-(1→2)- α -L-Rhap-1] →	Hachem et al.[17]
ALT-CSP	Rha, Fuc, Ara, Xyl, Gal, Glc in the ratios 14.5: 0.5 :68: 2.5 :11.5 :3 [b]	→ [4)-α -D-GalpA-(1] → [4)-α -D-GalpA-(1→2)- α -L-Rhap-1]→	

ALS-WSP	Rha, Ara, Xyl, Gal in the ratios 21.7: 64 :2 :12.5 [b]	→ [4)-α -D-GalpA-(1→2)- α -L-Rhap-1] →	Hachem et al.[16]
ALS-CSP	Rha, Ara, Xyl, Gal, Glc in the ratios 25.4 :12.7: 74: 1.5:10 :1 [b]		
A1OH	Ara, Rha, Xyl, Glc A, Gal A, Gal, Glc in the ratios 14:3:64:3:6:6:3 [a]	→4)- β –(D-Xylp)$_{4-6}$--(1→2)-*O*-(4-*O*-Me-α-D GlcpA →4)- β –(D-Xylp)$_{6-7}$-(1→2)-*O*-(4-*O*-Me-α-D GlcpA)$_2$	Ray et al.[27]
A4OH	Ara, Rha, Xyl, Glc A, Gal A, Gal, Glc in the ratios 9:2:80:2:3:2:2 [a]		
B1OH	Ara, Rha, Fuc, Xyl, Glc A, Gal A, Gal, Glc in the ratios 14:2:1:32:2:6:11:31 [a]	XXXG XXFG, XLXG/XXLG XLFG XUFG	
B4OH	Ara, Rha, Fuc, Xyl, Glc A, Gal A, Gal, Glc in the ratios 9:1:4:41:1:2:6:10:25 [a]		
PWSF-I	UA, Xyl in the ratios 22.6:76.4 [b]	→4)- β –(D-Xylp)$_7$-(1→2)-*O*-(4-*O*-Me-α-D GlcpA	Habibi and Vignon[26]
PWSF-II	UA, Xyl in the ratios 22.0:77.5 [b]		
PWSF-III	UA, Xyl in the ratios 22.5:77.3 [b]		
PWIF-I	UA, Xyl in the ratios 0:100 [b]	→ 4)- β -D- Xylp -(1→	
PWIF-II			
PWIF-III			
HX	Rha, Xyl, 4-*O*-Me GlcAin the ratios 0.7:98.6:0.7 [a]	→ 4)- β -D- Xylp -(1→	Barbat[25]
MGX A	Rha, Xyl, 4-*O*-Me GlcA in the ratios 0.9:85.8:13.3 [a]	→4)- β -D-Xylp-(1→2)-*O*-(4-*O*-Me-α-D GlcpA	
FI KOH	Rha, Ara, Xyl, Man, Gal, Glc, Gal A, Glc A, 4-*O*-Me Glc A in the ratios 4.3 :17.1 :58.1 :2.2 :1.5 :2.1 :5.4 :0.6 :8.7 [a]	→L-Ara- Xyl $_{3-6}$-4-*O*-Me-α–D-GlcA →4)- β –(D-Xylp)$_5$-(1→2)-*O*-(4-*O*-Me-α-D GlcpA)$_2$	Hachem et al.[24]
FIII KOH	Rha, Ara, Xyl, Man, Gal, Glc, Gal A, Glc A, 4-*O*-Me Glc A in the ratios 3.3 :20.4 :45.8 :8.1 :14.9 :2.3 :0.3 :1.9 :3.0 [a]	→L-Ara- Xyl $_{3-5}$-4-*O*-Me-α–D-GlcA	
FI NaOH	Rha, Ara, Xyl, Man, Gal, Glc, Gal A, Glc A, 4-*O*-Me Glc A in the ratios 4.3:16.1 :24.0 :24.1 :10.2 :6.8 :9.1 :2.6 :2.8 [a]	→L-Ara- Xyl $_{3-4}$-4-*O*-Me-α–D-GlcA	
FIII NaOH	Rha, Ara, Xyl, Man, Gal, Glc, Gal A, Glc A, 4-*O*-Me Glc A in the ratios 5.2 :15.8 :31.6 :19.3 :10.0 :10.9 :3.9 :1.2 :2.1 [a]		
FI KOH	Rha, Gal, Glc, Gal A in the ratios 31.6:1.9:1.9:62.5[a]	→ [4)-α -D-GalpA-(1→2)- α -L-Rhap-1]$_2$→	Hachem et al.[23]
FIII KOH	Rha, Xyl, Man, Gal, Glc, Gal A, Glc A, 4-*O*-Me Glc A in the ratios 17.1:11.2:0.0:9.2:4.0:48.5:7.3 [a]	→4)- β –(D-Xylp)$_3$-(1→2)-*O*-(4-*O*-Me-α-D GlcpA	
FI NaOH	Rha, Xyl, Man, Gal, Glc, Gal A, Glc A, 4-*O*-Me Glc A in the ratios 22.1:4.6:0.0:2.5:38.7:25.8:6.3 [a]		
FIII NaOH	Rha, Xyl, Man, Gal, Glc, Gal A, Glc A, 4-*O*-Me Glc A in the ratios 28.3:4.7:0.0:1.8:32.8:22.8:9.5 [a]		

[a]Mol percent; [b]Expressed in relative weight percentages; Rha: rhamnose; Ara: arabinose; Xyl: xylose; Glc: glucose; Gal: galactose; Man: mannose; Fuc: fucose; Gal A:galacturonic; Glc A: glucuronic acid; 4-*O*-Me Glc A: 4-*O*-methyl-glucuronic acid; nd = not determined.

Monosaccharide compositions

The composition of monosaccharides is usually analyzed by methods such as hydrolysis, derivatization and GC detection. A review of the published literature on the polysaccharides of *A. spinosa* indicates the presence of heteropolyoside structures which may have different monosaccharide compositions, which may be due to differences in the raw materials and their origin, the separation methods, the hydrolysis techniques employed and the detection methods used. The polysaccharides of *A. spinosa* are generally composed of arabinose, rhamnose, galactose and galacturonic acid for the pectic fractions. On the other hand, the hemicellulosic fractions are generally composed of xylose, glucose, 4-*O*-Me glucuronic acid, with different molar fractions of the different components according to the pectic fraction isolated.

Hachem et al.[16,17,18] used acid hydrolysis with trifluoroacetic acid (TFA) and GC analysis to separate, identify and characterize the water-soluble pectins (P_1-H2O, ALT-WSP and ALS-WSP) and the chelate-soluble pectins (P2-EDTA , ALT-WSP and ALS-WSP) extracted from the polysaccharide fractions of *A. spinosa.* Their results show that these fractions are essentially composed of arabinose and galactose with a small percentage of rhamnose. The molar ratios are almost similar in the different fractions, which may be due to the same purification conditions. The monosaccharide composition is similar to what has been found in previous studies. Aboughe-Angone *et al.*[19] obtained monosaccharide components of AFRG-I and AFRG-II which consisted of arabinose, galactose and rhamnose, arabinose which are the main components of the pectic polysaccharides of *A. spinosa*. Moreover, the enzyme treatment did not seem to

influence the monosaccharide compositions of the pectic fractions;–AFRG-I and AFRG-II were hydrolyzed with an endopolygalacturonase[19], and P_1-H2O, ALT-WSP while ALS-WSP, P_2-EDTA, ALT-WSP and ALS-WSP were hydrolyzed with TFA[16,17,18].

However, the enzyme treatment appears to affect the monosaccharide composition of the hemicellulosic fractions. The fractions FI KOH, FIII KOH, FI NaOH and FIII NaOH are essentially composed of xylose and arabinose according to the results of an enzymatic hydrolysis by an endoxylanase[24], as opposed to the acid hydrolysates of these fractions in which arabinose was completely absent[23]; While the fractions have been treated by similar isolation and purification processes, the differences can be attributed to the sensitivity of the few neutral monosaccharides such as arabinose and to the conditions of the acid hydrolysis which led to their degradation[31].

Chemical structures

The literature contains only few reports devoted to the chemical structures of polysaccharides extracted from *A. spinosa*. These structures are determined by classical methods, namely hydrolysis and methylation. They have been confirmed by MALDI-TOF mass spectrometry and NMR spectrometry.

Using NMR structural analysis, Hachem et al.[16,17] showed that the pectins of *A. spinosa* extracted with hot water are rhamnogalacturonan type I pectins with (1→4) galactanand (1→5) arabinanchains branched at the *O*-4 position of rhamnose units of the main rhamnosechain. However, chelate-extracted pectins contain homogalacturonan and a type I rhamnoglacturonan. The nature and type of linkages in the side chains are identical to those of all fractions. However, arabinose-rich type II rhamnoglacturonan May exist[19].

The analysis by MALDI TOF spectrometry allowed the determination of the compositions and structures of hemicelluloses of *A. spinosa*. This analysis confirmed the presence of a typical homoxylan (HX) consisting of unsubsituted β(1→4) xylopyranose chains [25,26] and of β(1→4) xylopyranose chains substituted at position 2 of xylose units by uronic acid optionally methylated with 4-*O*-methylglucuronic acid[25,26,27]or arabinose[24]. This is generally the case for most xylan-type hemicelluloses isolated from higher plants, some of which, however, may be substituted by 4-*O*-methylglucuronic acid. Indeed, it should be noted that only two uronic acids have been found in xylans isolated from *A. spinosa*. These results are similar to those already obtained with xylans from rapeseed stems[32] and quince seeds[33,34].

Aboughe-Angone et al.[19] and Ray et al.[27] demonstrated by MALDI-TOF and HPAE-PAD chromatography the presence of a XXGG xyloglucan-rich hemicellulose fraction generated by hydrolysis with endo-(1 → 4)-β-D –glucanase in addition to the XXXG, XXFG, XLXG/XXLG, XLFG fragments, previously characterized in various plants[35], a second group of fragments was detected. These latter fragments correspond to oligosaccharides homologous to XLXG, XLLG and XLFG in which a hexose is substituted by a pentose residue[27].

BIOACTIVITIES OF *ARGANIA SPINOSA* POLYSACCHARIDE

Pharmaceutical activity

In addition to the agri-food sector, more fundamental studies have reported biological activities likely to be of interest to the pharmaceutical industry. This is notably the case of antioxidant and anti-tumor properties.

Antioxidant activity

Research work on the antioxidant potential of polysaccharides is very recent. To our knowledge, no study has demonstrated such an activity of native polysaccharides or oligosaccharides, as their structures do not allow us to envisage this type of activity. The research focuses on the study of modified polysaccharides.

Hachem et al.[17] estimated the in vitro quenching activity of the polysaccharides AL-WSP and AL-CSP of *A. spinosa* on 2,2-diphenyl-1-picrylhydrazyl (DPPH) radicals by electron spin resonance (ESR). This study showed that these fractions were able to decrease the production of ROS and that they had a radical scavenging capacity with an antioxidant potential of up to 8%. This low potential can be explained by the extraction method, which can cause structural changes in the polysaccharides by generating new functions or by eliminating acetyl groups, thus affecting their biological properties[36,37].

However, this antioxidant activity is generally attributed to the presence of lignin in the polysaccharide fractions. Lignin is a phenol-rich polymer and examples of polysaccharides substituted by phenolic derivatives with good antioxidant activity can be found in the literature[38,39].

Anti-tumoral activity

Polysaccharides are molecules capable of fighting tumor lesions, thanks to their immunostimulant activity and have the advantage to be non-toxic[40,41].

Barbat[25] studied the effects of xylane-type polysaccharides (HX, MGX A) from *A. spinosa* on the multiplication of A431 tumor cells (a human vulvar squamous cell carcinoma line). The HX fractions of *A. spinosa* showed low cytotoxic activity (19%) and only at high concentrations while the MGX A fractions showed no dose-dependent effect and only weakly inhibited cell proliferation (29%). Comparison of the biological responses obtained with neutral HX and acidic MGX revealed an interesting relationship between PD, Xyl/MeGA ratio, MeGA distribution along the xylose skeleton and cytotoxic properties towards A431 cells.

Biosorbent activity

There are many examples in the literature of polysaccharide biosorbents that are capable of retaining metal cations,[42,43,44,45].

Hachem et al.[46] have characterized the biosorbent properties of the polysaccharides of the bark and the endocarp of Argan tree towards trace amounts of lead and cadmium. The study of the mechanism of interaction between the metal cations and biosorbents used was implemented by the Langmuir method[47]. The adsorption isotherms and their translation by the Langmuir model led to values of maximum adsorption capacity (q max) of 0.162 and 0.116 meq/g and affinity (b) of 1.58 and 2 for raw *A. spinosa* bark. 19 L/meq, whereas for the crude endocarp of *A. spinosa* at values of maximum adsorption capacity (q max) of 0.087 and 0.147 meq/g and affinity (b) of 0.27 and 0.35 L/meq for the cations Pb^{2+} and Cd^{2+} respectively. Hachem *et al*.[46] also showed that whatever the chemical modification considered (two selective oxidations, alone or in combination, of the following groups: primary alcohols with NaOBr catalyzed by (2,2,6,6-tetramethylpiperidin-1-yl)oxidanyl, and vicinal diols with periodate/chlorite.), the adsorption capacities of the trace metal elements were quantitatively improved at q max values of 0.865 and 0.211 meq/g for bark, 0.906 and 0.259 meq/g for the endocarp of *A. spinosa*, for the cations Pb^{2+} and Cd^{2+}, respectively.

CONCLUSIONS AND PERSPECTIVES

In conclusion, the isolation, purification and structural analysis of polysaccharides are very complicated due to the diversity and the complexity of these structures. Consequently, it is difficult to obtain homogeneous and active polysaccharide fractions. This is one of the main factors that hinders the development of polysaccharide research. Since there are many methods and approaches to study polysaccharides, researchers must carefully select the appropriate methods according to the specific properties/characteristics of the polysaccharide to be studied.

With the development and increasing attention paid to *A. spinosa*, its polysaccharides are more likely to become exploitable and have greater potential for use in different industries. However, due to the existence of multiple structural characteristics, the study of *A. spinosa* polysaccharides and the correlation between their biological effects and their structures has not been completely elucidated. Further research the structural features and the structure-function relationships is essential and deserves to be pursued to better understand the polysaccharides of this relict.

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