Pectins from *Opuntia spp.*: A Short Review[♦]

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SUMMARY

Two distinctive water-soluble high-molecular-weight pectic polysaccharide materials that occur in *Opuntia* cladodes and fruits have been extracted and studied in their chemical and rheological properties in our laboratory, namely, the well-known mucilage and a calcium-sensitive gelling fraction. Mucilage is present in the characteristic slimy fluid secreted by cladodes and fruits and it does not gel in the presence of calcium. Pectin of low degree of methoxyl occurs in the cell wall and can be extracted using a mild alkali process aided with a chelating agent. It shows remarkably good gelling properties in the presence of $CaCl_2$ by a cooperative Ca^{2+} "egg-box" binding mechanism. Although both materials share similarities in the composition profile of their neutral constituent sugar residues, pectin has a significantly greater amount of linear polygalacturonic acid. This difference causes very different physicochemical and functional properties underlying the potential applications of these polysaccharides in a wide variety of fields (e.g., foods, biotechnology, medicine).

DEFINITION OF TERMS

Pectin substances are a large family of structural elements of primary cell walls and intercellular regions of higher plants where they function as hydrating agent and cementing material of the cellulosic network. Figure 1 is a schematic view of the molecular architecture of the cell wall. They are commonly produced during the initial stages of primary cell growth and make about one third of the cell-wall dry substances. The highest concentration of pectins in the cell wall is seen in the middle lamella, with a gradual decrease from the primary cell wall toward the plasma membrane. Pectins are among the cell-wall components whose collective ability to contain the turgor pressure of the cell wall determines its growth (Jarvis 1984). The term pectin substance is commonly used to encompass the methoxyl ester pectin, the deesterified pectic acid and its salts, pectates. Other neutral polysaccharides like arabinans, arabinogalactans, and galactans lacking the galacturonan backbone are often found in association with pectic substances in the wall (McCann and Roberts 1991; O'Neill *et al.* 1990). Contradictory, these arabinan and galactan polymers in pea cell walls have been demonstrated to occur in the hemicellulose fraction not covalently or ester-linked to pectic substances (Talbot and Ray 1992). The unspecific term "protopectin" is often used to designate the native pectin fractions in cell walls that cannot be extracted by nondegradative methods.
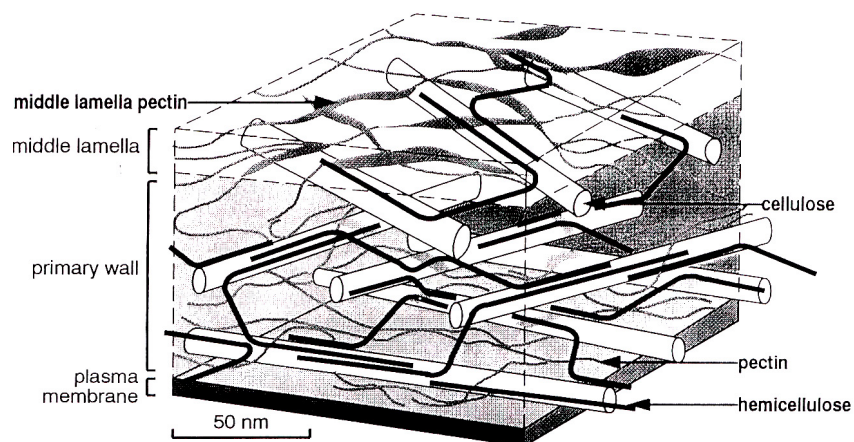

[♦] Received 19 February 2003

Figure 1. Simplified and Schematic Representation of the Architecture of the Cell Wall. Cellulose microfibrils appear crosslinked by hemicellulosic polymers. Pectins present in the middle lamella are Ca^{2+} crosslinked to each other (McCann and Roberts 1991).

Chemical Structure of Isolated Pectins

Chemically, pectins are a family of complex heteropolysaccharides comprised by a diversity of carbohydrate residues. Like most other plant polysaccharides, pectins are polydisperse in composition and molecular size, that is, they are heterogeneous with respect to both chemical structure and molecular weight. Their composition varies with the source and conditions of extraction, location, and other environmental factors (Chang *et al.* 1994). The main component common to most pectins is a backbone chain structure of α-(1→4)-linked D-galacturonic acid units interrupted by the insertion of (1→2)-linked L-rhamnopyranosyl residues in adjacent or alternate positions (Aspinall 1980). The amount of rhamnose in pectins is typically 1% to 4% These linear segments consisting predominantly of galacturonan are called homogalacturonans. The degree of polymerization (DP) of uninterrupted galacturonosyl regions in homogalacturonan segments from apple, beet, and citrus lies in the range of 70 to 100 (Thibault *et al.* 1993). Another important feature of galacturonans is the esterification of carboxylic groups in galacturonic acid residues with methanol and in certain pectins, their hydroxyl groups are also partially acetylated. The degree of methylation (DM) is defined as the number of moles of methanol per 100 moles of galacturonic acid. Pectins are called high-methoxyl (HM) pectins when the value for DM is 50 or higher. While when DM is below 50, the pectin is called low-methoxyl (LM) pectin. When less than 10% of the carboxyl groups are methylated, one speaks of pectic acid. The degree of acetylation (DAc) is defined as the percentage of galacturonosyl residues esterified with one acetyl group. DAc is generally low in native pectins, ranging between 3% and 15% (Voragen *et al.* 1995). The botanic origin and the extraction procedure determine the content of galacturonic acid, DM, and DAc in pectins.

Other constituent sugars are attached in side chains, the most common being D-galactose, L-arabinose, and D-xylose. D-glucose, D-mannose, L-fucose, and D-glucuronic acid are found less frequently. The major sugars, D-galactose and L-arabinose, are present in more complex chains with structures similar to those of arabinans and arabinogalactans and with chain lengths that can be considerably large.

Pectins in *Opuntia* spp.

The occurrence of pectins in various *Opuntia* species from Mexico has been documented for almost three decades (Villarreal *et al.* 1963). Table 1 shows data from such early studies in which the pectin contents found in eight species and varieties of *Opuntia* were compared. The yield of soluble pectin in these samples was within a wide range of 0.13% to 2.64% in wet basis (1.00% to 23.87% in dry-weight basis).

Attention is drawn to the high pectin content found for *O. robusta* (known as "nopal camueso") in comparison with *O. ficus indica* and the other species. It is interesting to note that the pectin content in *O. robusta* is within the range reported for citrus peel (20% to 30% d.m.b.), an industrial source of pectin. At present, apple pomace and citrus peels are the main sources of commercially acceptable pectins. Other sources of pectins that have been considered are sugar beet and residues from the seed heads of sunflowers. From this comparison, it is clear that *Opuntia spp.* can be regarded as a promising commercial source of industrial pectins. Nevertheless, many other technical and economic considerations beside pectin content must be made carefully in order to appraise the viability of cactus pectin industrialization.

Table 1. Pectin Content in Some *Opuntia* Species and in Some Fruits

Species	Total Pectin (%)		Protopectin (%)		Soluble Pectin (%)	
	Wet Weight	Dry Weight	Wet Weight	Dry Weight	Wet Weight	Dry Weight
Opuntia ficus-indica var I[a]	1.91	13.84	0.097	3.56	1.418	10.28
O. ficus-indica var II[a]	1.10	8.39	0.622	4.74	0.478	3.65
O. spp. *(Blanca I)*[a]	0.95	7.6	0.448	3.58	0.482	4.02
O. spp *(Blanca II)*[a]	0.84	7.05	0.721	6.05	0.129	1.00
O. amylacea[a]	1.40	9.58	0.685	4.69	0.715	4.89
O. megacantha[a]	0.80	5.06	0.586	3.43	0.279	1.63
O. steptracantha[a]	0.97	6.59	0.605	4.38	0.365	2.21
O. robusta[a]	3.30	26.61	0.653	5.26	2.64	23.87
Apple pomace[b,c]	0.5-1.6	10-15	------	------	------	------
Citrus peel[c]	------	20-30	------	------	------	------
Sugar-beet pulp[b]	1.00	------	------	------	------	------

[a] Data from (Villarreal *et al.* 1963)
[b] Data from (Renard and Thibault 1993)
[c] Data from (Rolin 1993)

Diced cactus pads heated at 85°C for 20 min.

Neutralised to pH 7-7.5 with NaOH

Liquidization and centrifugation

PRECIPITATE (**GE**)   SUPERNATANT (**NE**)

Suspention in 50mM NaOH, containig 0.75% sodium   Addition of NaCl to 1M
hexametaphospate, stir x 1h

Filtration. Adjust pH of supernatant to 2 with HCl,
stir for 10 min and let to precipitate

Centrifuge   Filtration through 3μm membrane

Redispersion of the precipitate in H$_2$O,
Adjust pH to 8 with NaOH

Filtration with 3, 1.2, 0.8
and 0.45 μm membranes

Precipitation with ethanol 50% v/v

Centrifugation

Washing in ethanol/H$_2$O mixtures (70, 80, 90, 95 y 100% v/v)
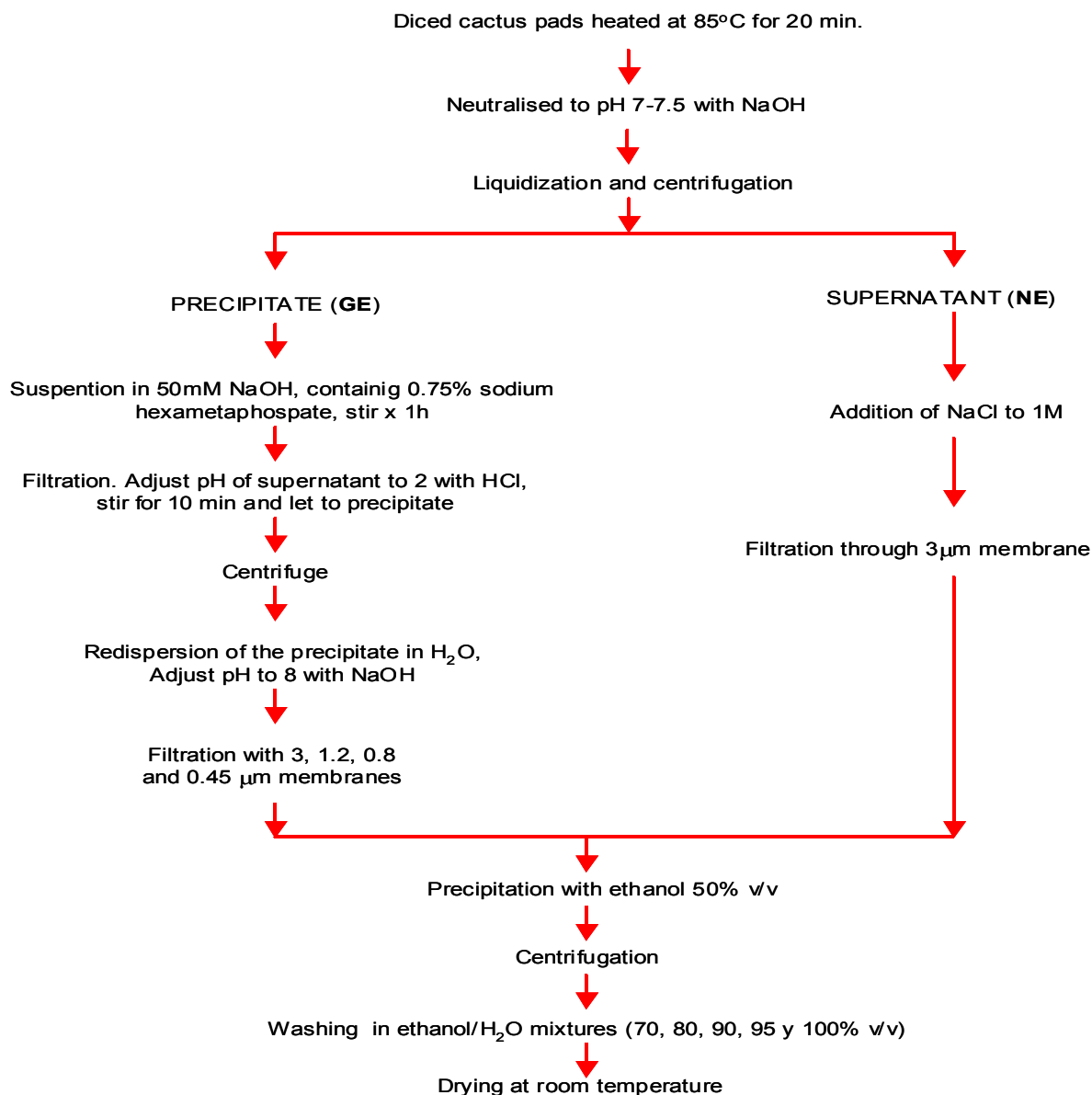
Drying at room temperature

Figure 2. Laboratory-Scale Extraction Protocols for the Isolation and Purification of Pectins from *Opuntia* Cladodes, Namely a Gelling Extract (GE) and a Neutral Nongelling Mucilage Extract (NE)

In a recent study completed in our laboratory, we succeeded in extracting a pectin with gelling capacity and a nongelling mucilage fraction from *O. ficus-indica* cladodes. The extraction protocol adopted for the isolation of these two distinctive pectic substances is outlined in Figure 2. The protocol included the use of a calcium-sequestering agent in alkali conditions, which ensured the best chelating performance (Cárdenas *et al.* 2003).

The chemical composition of the gelling extract (GE) was found to be markedly different from that of the mucilage material (NE extract) reported by independent groups in Mexico (Medina-Torres *et al.* 2000) and France (Majdoub *et al.* 2001). This comparison is summarized in Table 2.

Table 2. Sugar Composition of *Opuntia ficus-indica* Pectin Extract Obtained by Alkaline Process Aided With a Sequestering Agent and Cactus and Prickly-Pear Pectic Extracts Previously Studied (% in weight)

Characteristic	Pectin Gelling Extract (GE) (this work)	Prickly-Pear-Peel Pectin (acid process)[a]	Mucilage Extract (NE) (this work)	Lyophilized Mucilage[b]	Mucilage Precipitated in Isopropanol/ Acetone[c]
Uronic acids[d]	56.3	64.0	11.0	19.4	6.4
Rhamnose[d]	0.5	0	1.75	6.9	7.0
Arabinose[d]	5.6	6.0	17.93	33.1	44.0
Galactose[d]	6.5	22.0	20.99	20.3	20.4
Glucose[d]	0	2.6	0	1	0
Xylose[d]	0.9	2.1	3.06	18.7	22.1
Degree of esterification	0	------	------	------	------
Intrinsic viscosity (ml/g)[e]	234	------	1050	840	------
Yield (%, p/p)	0.6	0.12	0.07	------	------

[a] Data taken from (Forni *et al.* 1994)
[b] Data taken from (Majdoub *et al.* 2001)
[c] Data taken from (Medina-Torres *et al.* 2000)
[d] Glucuronic + galacturonic acid
[e] Determined in 0.1M NaCl at 20°C

In general, the neutral-sugars content of nopal pectin was lower than that reported for pectins of other sources. This, together with the low rhamnose content, may be suggestive of the existence of regions of long chain segments of polygalacturonate (homogalacturonan), which are essential to the gelling process, as it is further discussed below. While the content of uronic acids in cactus pectin compared well with that of the tuna-peel pectin obtained by an acidic process, it was notably superior to that of mucilage extracts which do not have a demonstrated gelling capacity in the presence of Ca^{2+}. In general, the overall composition profile of the cactus pectin composition coincides well with that of pectin obtained from lemon-peel pectin (Ros *et al.* 1996) and sugar beet (Oosterveld *et al.* 2000). A negligible DM value was analyzed in a film of the GE material using Fourier-transformed infrared spectroscopy (FTIR) (Cárdenas *et al.* 2003), suggestive that all esterified methyl groups were saponificated during the extraction procedure.

The chemical composition of mucilage of *Opuntia ficus-indica*, in turn, has also long been studied using different chromatographic techniques (Amin *et al.* 1970; McGarvie and Parolis 1979, 1979, 1981, 1981; Trachtenberg and Mayer 1981). In general, the stems of cactus contain varying proportions of D-galactose, L-arabinose (pyranose and furanose forms), D-xylose, and L-rhamnose and as the major neutral sugar units as well as D-galacturonic acid. The suggested primary structure describes the mucilage as a linear repeating "core" chain of (1→4)-linked β-D-galacturonic acid and α(1→2)-linked L-rhamnose with trisaccharide side chains of β(1→6)-linked D-galactose attached at O(4) of L-rhamnose residues (McGarvie and Parolis 1979, 1981, 1981). The galactose side residues present further branching in either O(3) or both O(3) and O(4) positions. The composition of these acid-labile peripheral chains is complex; at least 20 different types of oligosaccharides (mostly as disaccharides and trisaccharides) have been identified (McGarvie and Parolis 1981). These, invariably containing L-arabinose residues present as (1→5)-linked residues and possibly as branch points and single D-xylose groups, occur as end-groups, to

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give a xylose-to-arabinose ratio of ~1:2. This ratio seems to hold in close agreement with data for mucilage extracts analyzed in the more recent studies of Brito and co-workers (Medina-Torres *et al.* 2000) (xyl:ara ~1.8) and Majdoub et al. (Majdoub *et al.* 2001) (xyl:ara ~2.0), but not with our own extract (xyl:ara ~0.17) included in Table 2. This chemical composition shows great similarities to that of the highly branched regions ("hairy" regions) of cell-wall pectins, particularly to the rhamnogalacturonan I (RG-I) fraction (Pellerin *et al.* 1996; Voragen *et al.* 1995). In light of this close resemblance, mucilage from *Opuntia* and other cacti, are indistinctly referred to as pectins. However, up to now, the mucilage polysaccharides in *Opuntia*, do not seem to be chemically associated, either covalently or otherwise, to the structural cell-wall pectins. Instead, it has been proposed that mucilage biosynthesis takes place in specialized cells which excrete it into the apoplast where it helps to regulate the cellular water content during the initial phase of dehydration (Nobel *et al.* 1992). Its physiological role has been associated with their ability to bind water under unfavorable climatic conditions (Mindt *et al.* 1975). It has also been suggested that the mucilage has a predominant role in the Ca^{2+} economy of the plant (Trachtenberg and Mayer 1981). The major characteristics of these two distinctive families of polysaccharides are reviewed in the following sections.

Properties of Nopal Mucilage
Majdoub *et al.* (2001), have recently addressed the problem of trying to understand the relationship between the structure and the properties of the pectin of peeled prickly pear. The material that these authors evaluated was the aqueous extract of macerated peeled nopals. Its composition is shown in Table 2. Two polymeric components were identified in the purified extract by size-exclusion chromatography (SEC) coupled to double detection by refractive index (RI) and multiangle laser light scattering (MALLS) in 0.1M $LiNO_3$, namely a high-molecular-weight fraction (~10% by weight) and a low-molecular-weight fraction (~90% by weight). The two populations of molecular species were separated satisfactorily in a different experiment by subjecting the native sample to ultrafiltration against deionized water during a week and using a series of membranes with a molecular weight cut-off of 100,000 g mol^{-1}. The material retained by the membrane (HWS) had a high weight-average molar mass (M_w~14.2 × 10^6), while the filtrate (LWS) had a low M_w~4000. LWS comprised predominantly protein species (~80% by weight), while no protein was detected in the HWS fraction. Therefore, the major components of the native mucilage extract are low-molecular-weight proteins. Although it is not explicitly discussed in the paper of Majdoub *et al.* (2001), the likely reason why proteins are not removed during the extraction is that the extract was not precipitated with ethanol (*cf*. Figure 2). The nature of the proteins present in nonprecipitated nopal mucilage extract is mostly unknown and from their size and poor water solubility only inferences have been made, so that they have been compared with the 2S albumin storage family proteins present in the seeds of *O. ficus-indica* (Uschoa *et al.* 1998). That proteins are essentially associated only to LWS, was demonstrated by an experiment in which the native sample was subjected to the activity of pronase. Only species in LWS were hydrolyzed, while HWS polysaccharide fraction was not affected. The resistance of HWS to pronase activity is in contrast with the well-known arabinogalactan protein (AGP) complex present in gum arabic, in which the protein species are associated to the high-molecular-weight fractions (Connolly *et al.* 1988). AGP macromolecular assemblies of varying molecular size in gum arabic are key to its unique functionality, namely, the capacity to lower the oil-water interfacial tension, and hence to create the emulsifying capacity in oil-in-water emulsions (Dickinson and Galazka 1991; Dickinson *et al.* 1991; Ray *et al.* 1995). Nevertheless, proteins themselves are also known to be effective emulsifiers, hence, the potential surface activity of nopal mucilage cannot be ruled out on these grounds. To our knowledge, the surface properties of nopal mucilage so far have not been tested.
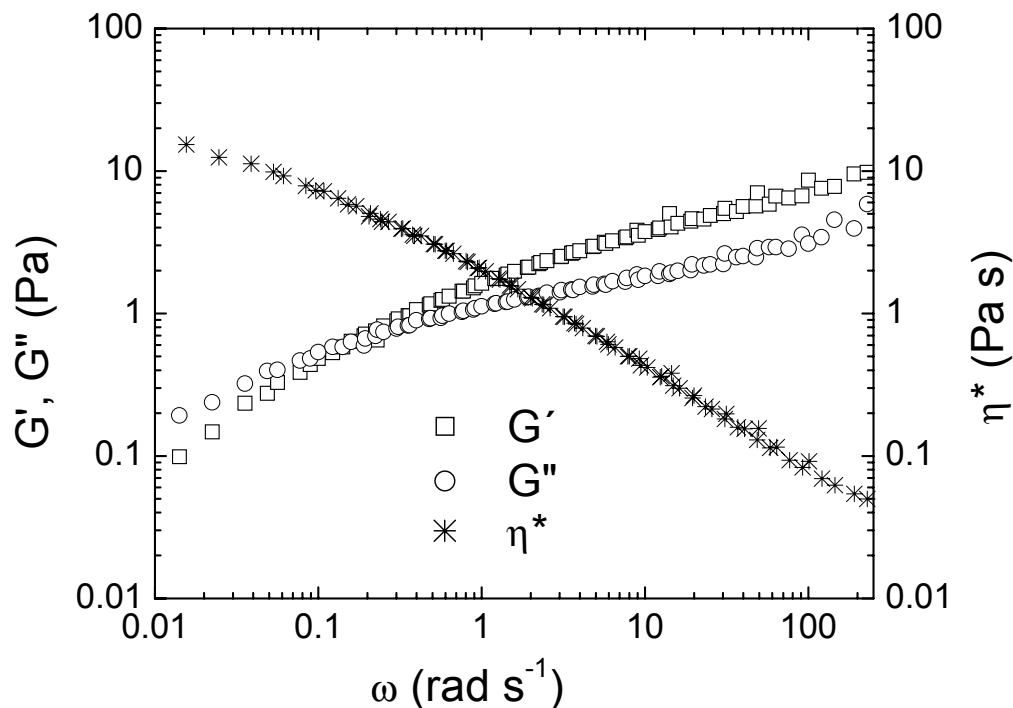
Figure 3. Dependence of the viscoelastic storage, G' (□), and loss, G'' (o), moduli and complex viscosity, η* (*), obtained by time-temperature superposition of 1.3% (w/v) nopal mucilage extract in 0.1 M NaCl; reference temperature: 20°C. Measurements were recorded by registering frequency sweeps between 5°C and 50°C (frequency = 0.1 to 100 rad/s; γ = 5%).

Yet another important issue with regard to the proteins in nopal extracts has been addressed in separate studies. It has been demonstrated that extracts of fruits of *O. ficus indica*, have high enzymatic activity towards the hydrolysis of $_s$- and -caseins from bovine, caprine and ovine milk leading to clotting. The activity displayed by these extracts is almost identical to that of animal rennet (Pintado *et al.* 2001; Texeira *et al.* 2000). Whether this caseinolytic activity is also present in aqueous extracts of nopal cladodes or only in the fruit is yet to be demonstrated.

The rheological properties of various nopal mucilage pectin extracts have been addressed by various groups using small- and large-deformation techniques (Cárdenas *et al.* 1997; Majdoub *et al.* 2001; Medina-Torres *et al.* 2000). In our own studies, we have addressed the rheological properties of the mucilage extract (NE) obtained according to the layout described in Figure 2. To this end, data of small deformation (oscillatory shear) rheology recorded at various temperatures in the range between 5°C and 50 C were utilized to construct a time-temperature superposition master curve at 20 C (Figure 3). The mechanical viscoelastic response observed in F i g u r e 3, corresponds with that of an entangled network of disordered polymer coils. In turn, Majdoub *et al.* (2001), have evaluated the effect of adding different types of salts on the viscosity of HWS extract. The flow behavior of HWS concentrated (30 g/l) solutions were compared in pure water and in the presence of $CaCl_2$ or $LiNO_3$. When compared to the 'zero' shear rate viscosity value (η_o) of the solution in pure water, the loss in viscosity observed in the presence of the monovalent cation (Li^+) is less marked than the one corresponding to the same solution (*i.e.* identical polymer and electrolyte concentration) in the presence of divalent cation (Ca^{2+}).

This effect has been interpreted by the authors as the result of the complex formation between the calcium ions and the carboxylic groups located along the polymer backbone invoking the established "egg-box" interaction known to underlie the gelation of alginate and pectin in the presence of certain divalent cations

(Morris *et al.* 1982). However, as the authors also point out, this interaction leads to massive increase in viscosity and gel formation and not to a reduction in viscosity as observed. Yet, they claim that in their system the interaction with Ca^{2+} acts through intramolecular bonds, thus effectively inducing a contraction of the polymer coil. In our view, the interaction between the mucilage and either monovalent or divalent cations, is due to merely ionic condensation of the dissociated ions into the polyelectrolyte. Screening of charges in the polyelectrolyte is known to drive the polymer coil to a more compact conformation. In the following section we document and discuss the interaction between gelling pectin and Ca^{2+} and that this interaction is concomitant with a dramatic change in rheological properties, a behavior which is completely different in kind to that documented for the HWS mucilage.

Gelling Properties of Nopal Pectin
Up to now, most of the research conducted on cactus pectins has addressed the physicochemical and physiological properties of mucilage-type polysaccharides. These pectins do not form gels and only increase the viscosity of the solution as discussed above. However, pectin in the food industry is best known as a gelling agent. Indeed, depending on DM, pectins can form aqueous gels in an acid medium and under high sugar concentrations (high DM pectins, DM >50%) or by interaction with divalent cations, particularly Ca^{2+} (low DM pectins, DM <50%). These two distinctive mechanisms of gelation, lead to a wide range of commercial applications that each family of pectins finds. The largest single application of pectin is in fruit preserves, namely, in jams, jellies, and marmalades where it used in levels ranging from 0.03% to 0.1%, depending on the fruit type and the total solids content. The choice of pectin type depends both on product type and process (May 1997).

The laboratory-scale process to isolate and purify the pectins from nopal, shown in Figure 2, afforded a very low DM pectin (extract GE), strictly, sodium pectate. We have investigated the rheological properties of this gelling extract in gel model systems in the presence of varying concentrations of Ca^{2+}. To this end, the level of calcium added was adjusted according to the stoichiometric conversion, R (= $2[Ca^{2+}]/[COO^-]$), of calcium-polygalacturonate so as to give R values of 0.10, 0.29, 0.49, and 0.59 (Cárdenas *et al.* 2003).

Figure 4 illustrates the formation and melting of a representative gel of nopal pectin at Ca^{2+} level, R = 0.39, during controlled cooling and heating in a rheometer. The evolution of the elastic, G', and viscous G", viscoelastic moduli, during cooling shows a monotonic sigmoidal curve for the elevation of both moduli in the range of ~40°C to 10°C. Indeed, the shape of the G' and G" temperature traces has all the hallmarks of a sol-gel transition accompanied by a coil-helix conformational change. This phase transition is similar in kind to that which determines the gelling behavior of other food polysaccharides, notably agarose (Mohammed *et al.* 1998), κ-carrageen (Piculell *et al.* 1997), and gellan (Nishinari 1996). In these systems, gelling occurs as a highly cooperative process governed by the establishment of ordered, helix structures stabilized by a profuse hydrogen-bonded network. As in some of these systems (e.g. κ-carrageenan and gellan), the onset temperature of gelation (or setting temperature) for nopal pectin gels is controlled by the ionic concentration of $[Ca^{2+}]$. The molecular origin of the gelling interaction of low-methoxyl nopal pectin and calcium is the set up of an ordered three-dimensional network crosslinked by Ca^{2+} forming the so-called "egg-box" junction zones, in which each two carboxylic groups present in two polygalacturonic chains form a coordination complex with a calcium ion (Grant *et al.* 1973; Morris *et al.* 1982). Typically, these junction zones involve a sequence of 20, or more, pairs of galacturonic acid groups crosslinked by calcium ions (like eggs between two boxes). Indeed, this model used to account for the gelation of pectin (and alginates as well) is still the soundest one to explain the reactivity of low methoxyl pectins to calcium.
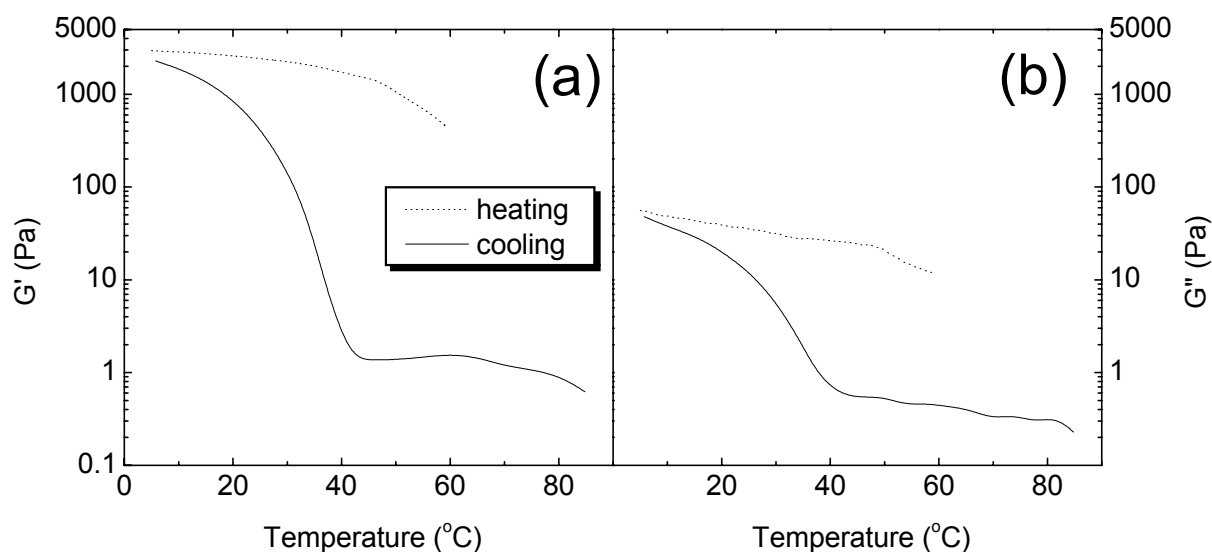
Figure 4. Evolution of the storage (G') and loss (G") mechanical modules ($\omega = 1$ rad/s, $\gamma = 0.05$) during cooling (continuous line) and heating (dotted line) for cactus pectin gels at R = 0.39 calcium level.

Although the complex behavior of pectin gels documented here may sound rather daunting, the practical significance of these phenomena make low-methoxyl nopal pectin a very versatile and controllable system in the hands of a technologist who has an understanding of the basic properties and experience of handling them in practice, and many attractive products can be produced. In addition to fruit preserves mentioned before, pectins are actively used in the development of many more formulations. Just to name a few: desserts, confectioneries, dairy drinks (yogurt drinks, whey, drinks, milk/juice blends) and low-calorie drinks.

Nopal pectin extracts also find use in other nonfood applications, such as in cosmetics, particularly in soaps, creams, and shampoo where it is used as a moisturizing agent. In the industry of construction materials nopal pectins have an enormous potential. Nopal mucilage extract is mixed with lime to produce mortar used in the protection and restoration of historical monuments (Cárdenas *et al.* 1998). Also, in Mexico and Peru, over centuries adobe has been blended with the mucilage of *Opuntia ficus-indica*. This traditional stabilization technique not only increases adobe's resistance to water, it also engenders considerable improvement in its compressive strength (Bati and Rovero 2001).

Physiological Properties of Pectin
As a final remark, we considered that it is important to include a brief section on the physiological effects of pectin and its possible relation with the advocated health benefits associated with the intake of "nopalitos" and prickly pear. In nutrition, pectin is regarded as nonstarch polysaccharides soluble "dietary fibre".

It has been demonstrated experimentally that the intake of isolated prickly-pear pectin decreases plasma low-density lipoprotein (LDL) cholesterol levels in guinea pigs as a good model to human plasma lipoprotein profile, distribution of the hepatic free and esterified cholesterol pools, and the relative activities of the hepatic enzymes (Fernandez *et al.* 1994; Fernandez *et al.* 1990). From these studies, it was demonstrated that the hypocholesterolemic effects of prickly pear pectin on hepatic and plasma cholesterol concentrations do not result from a significant reduction in exogenous cholesterol absorption.

However, intake of prickly pear pectin does lower hepatic cholesterol concentrations by as yet undefined mechanisms, resulting in effects on hepatic cholesterol homeostasis and on plasma LDL concentration. These decreases in hepatic cholesterol increase apo B/E receptor expression, tend to lower hepatic ACAT (acyl CoA:cholestrerol acyltransferase), and do not change HMG-CoA (3-hydroxy-3-methylglutaryl CoA) reductase activity, key enzymes of cholesterol esterification and synthesis, respectively. These changes in hepatic cholesterol homeostasis have a major effect on plasma LDL cholesterol concentrations.

In patients suffering from non-insulin-dependent diabetes mellitus (NIDDM), the hypoglycemic effect of *Opuntia streptacantha* (Ibañez-Camacho and Roman-Ramos 1979) has long been documented. As in the case of the hypocholesterolemic effects, the responsible mechanisms have not been established.

Other effects of the intake of nopal pectin, that have been demonstrated include anti-inflammatory activity for the treatment of enteritis (Angulo *et al.* 2001). The intake of citrus pectin has been associated with anticarcinogenic effects (Inohara 1994; Pienta 1995; Platt 1992). Though, no similar effects have so far been demonstrated in cactus pectin, Palevitch *et al.* (1993) have accounted for the use of *O. ficus-indica* in the relief of the symptoms caused by benign prostatic hypertrophy.

Undoubtedly, the whole subject area concerned with physiological effects of cactus pectins is complex and the underlying mechanisms are still poorly understood. Meanwhile, in the expanding market of dietary supplements, the number of products based on *Opuntia spp.*, namely, tablets and soft drinks is growing rapidly.

CONCLUSIONS

Pectin is widely used as a texturizer and stabilizer in a variety of foods and other industries. Despite its availability in a large number of plant species, commercial sources of pectin are very limited. Therefore, cactus appears to be a very promising new source of these biopolymers. The two distinctive categories of pectic polysaccharides that occur in the cladodes and in prickly pear span a plethora of physicochemical properties yet to be exploited in various fields of applications in food, dietary supplements, medicine, pharmacy, and materials development, among other. Gelling capacity in the presence of calcium demonstrated in nopal pectin is certainly one of the key properties in this regard. High-methoxyl pectin in cactus also must be available in the native state, although the process to extract it is yet to be established.

ACKNOWLEDGMENTS

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