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Research Article

Chemical Composition, Functional Properties, and Effect of Inulin from Tunisian *Agave americana* L. Leaves on Textural Qualities of Pectin Gel

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In this study, the chemical composition and functional properties of *Agave americana* L. (AA) leaves were determined. The *Agave* leaves powder had a high amount of total dietary fiber (38.40%), total sugars (45.83%), and protein (35.33%), with a relatively low content in ash (5.94%) and lipid (2.03%). The *Agave* leaves were exhibited with potential food application. The *Agave* inulin showed a significant difference compared with the commercial inulin as for aw (0.275 against 0.282), pH (5.53 against 5.98), ash (2.89% against 1.19%), protein (3.46% against 1.58%), water holding capacity (2.42% against 1.59%), solubility (73 g/L against 113 g/L), and emulsion capacity (14.48% against 21.42%), respectively. The textural properties of *Agave* inulin-pectin mixed gels were examined using instrumental Texture Profile Analysis (TPA). Firmness of the prepared *Agave* inulin-pectin mixed gels was lower than the pectin gel (0.3554 N against 5.7238 N, resp.). This reduction of firmness showed a synergetic effect between pectin and inulin. These results suggested a positive interaction between *Agave* inulin and pectin to decrease the firmness of mixed gels and open a good alternative to obtain value added products from this resource.

1. Introduction

Agave is usually thrived in semiarid regions such as Mexico, Australia, and Africa. Commonly grown species include *Agave americana* L., *Agave attenuata*, and *Agave tequilana*. Different from other *Agave* species, AA L. has a large asparagus-like flower stalk, but no piñas. Because of no piñas (a reservoir of fructans), the AA is commercially less valuable for the production of alcoholic beverages, compared to other *Agave* species such as *Agave tequilana* and *Agave attenuate*, although its leaves can be used for pulque (a beer-like drink) production. *Agave* is the biggest genus that identifies a group of desert plants belonging to the monocotyledonous family called Agaveceae [1]. This genus is characterized by spiny leaves yielding various types of fibers and composed of wild plants that do not need tender care and are traditionally used as source of fibers. The North American AA plant is a species belonging to such a genus, which is also flourishing in South of Africa as well as the Mediterranean area [2]. Various species of *Agave* are used in the traditional medicine either as medicinal plants or as good anti-inflammatory agents [3, 4]. Uribe and Saldivar [5] confirmed the anticancerogenic and antioxidant properties of the *Agave* syrup. This plant has been shown to have both antibacterial and antifungal properties [6]. Moreover, the leaf of AA base contains up to 16% of fructans. Pina and leaf base can be used for the commercial production of fructans and long-chain inulin, which can be used as vaccine adjuvant in the pharmaceutical industry [7]. This *Agave* plant is native to Mexico and other parts of the Caribbean area [8, 9]. Plants were taken from there to Europe, Africa, and the Far-East by the Spanish and Portuguese, where they naturalized rapidly, especially in the high arid regions around the shores of the Mediterranean [10].

In Tunisia, the AA is the most abundant variety of *Agave* [11]. This variety is characterized by the fact that it is a much voluminous plant with long, fleshy, rigid, hard-surfigured, and lanceolate leaves growing directly out from the central stalk to form a dense rosette. Its floral stalk, sometimes

termed the trunk, can reach 10 to 20 m of length. Evaluation of AA as a source of fiber was launched recently in Tunisia, where fibers are extracted traditionally and used for making twines and ropes [12]. The AA was much used by Tunisians for its fibers when fibers extracted by simple immersion in seawater were used to make ropes and twines for agricultural, marine purposes and known for its wealth of structural insoluble polysaccharides [13] and soluble polysaccharides [14]. Thus, it would be wise to valorise any noble fractions of AA.

On the other hand, inulin is the second polysaccharide reserve most abundant after starch. It is the main reserve carbohydrate [15–17]. It can be found, for instance, in onions (1–5% on a fresh weight basis), garlic (4–12%), banana (0.2%), and chicory roots (15–20%). Indeed, by its chemical structure, inulin is not hydrolysed or absorbed in the small intestine, and then it is considered a soluble fiber that can be incorporated into various food products. Its low sweetness and its properties similar to sucrose allow it to replace sugar in some formulations. inulin stimulates the growth of bifidobacteria, which is believed to have health-promoting functions. Many other health enhancing aspects of inulin concern diabetes, lipid metabolism, cancer prevention, and antiulcer activity [18, 19].

The technological use of inulin is based on its properties as a sugar replacer (especially in combination with high intensity sweeteners), as a fat replacer and texture modifier. For fat replacement in low-fat dairy products inulin seems particularly suitable as it may contribute to an improved mouthfeel. Also, inulin was used to improve rheological characteristics and nutritional properties of food and to be classified among functional foods [20].

Inulin gel formation is different from that obtained with hydrocolloids. inulin forms particle gels, whereas the increase of viscosity through most hydrocolloids is obtained by bonds between chains [21]. Rheological properties of inulin are quite well documented in the literature [22–24]. Interactions of inulin with some carbohydrates such as maize starch, maltodextrins, or pectin have also been analysed [24–26].

Gelling properties of pectin may be affected by many factors. Increased degree of methoxylation (DM) resulted in higher setting temperature and so more rapid gel formation for high methoxyl pectin (PHM) [27]. C. Rolin and J. de vries [28] reported that calcium addition also influences gel formation behaviour of PHM [28]. Moreover, gelling temperature increases in the presence of Ca^{2+}. Calcium content influences also the rheological behaviour of low methoxyl (LM) pectin gels by increasing G' (elastic modulus), but at Ca^{2+} levels that are too high, syneresis may occur. Contrarily to PHM, the gel temperature increases with decreasing DM. In addition, LM pectin with a blockwise distribution of free carboxyl groups is very sensitive to calcium [29].

Interactions between mixed biopolymer systems of which pectin is one component have been largely studied, such as pectin/alginate [30], pectin/starch [31], and pectin/gelatine [32] mixtures. However, few studies exist on the behaviour of mixed inulin-pectin gels. Pectin mixtures are widely used in food applications to obtain products with better properties.

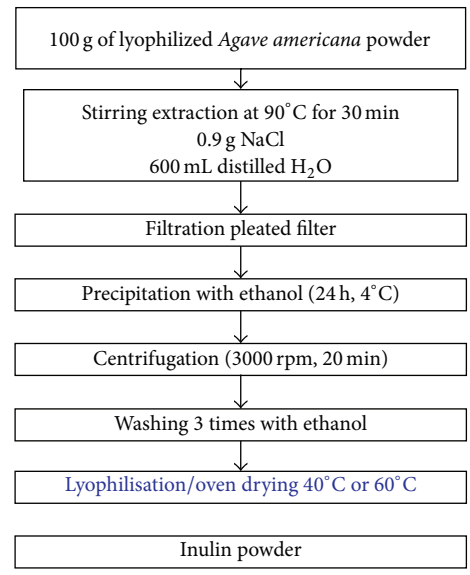

Figure 1: Extraction diagram of inulin from *Agave americana* L.

The aim of the present work is to characterize leaves powder and inulin from the AA and next to study the synergistic effect of inulin on pectin gel for food preparations.

2. Materials and Methods

2.1. Origin of Materials. AA plants cultivated organically were collected at the same time from the same cultivation zone (M'saken, Sousse, Tunisia). Leaves were obtained from plants at the same stage of maturation. In this work, the basal leaves of AA were used. 5 kg of leaves is cut into large pieces and stored at −20°C until use for the different analyses.

The pectin (high methyl pectin (PHM), medium rapid set) was supplied by Zina company, Sfax, Tunisia.

2.2. Preparation of the Sampling. At the first step, AA leaves were washed with water and the chlorophyll cuticle is removed. Then, the leaves are cut into small pieces and milled using a laboratory mixer. After that, the resulting biomass was lyophilized and stored at 4°C until the analysis.

2.3. Extraction Process. The inulin from AA leaves was extracted by mixing 600 mL of distilled water per 100 g of sample and the mixture was blended in a mechanical device made of stainless steel with 0.9 g of salt/L and then stirred at 90°C for 30 min (Figure 1). The suspension was filtered on canvas and then the supernatant was filtered under vacuum with Whatman paper. The filtrate was precipitated with ethanol (90%) overnight at 4°C and centrifuged at 3000 rpm for 20 minutes. The obtained pellet was subjected to three washes with ethanol, lyophilized or oven dryed at 40°C/60°C, and stored in desiccators until they were analysed [33, 34].

2.4. Chemical Composition. All analytical determinations were performed at least in triplicate. Values of different

parameters were expressed as the mean ± standard deviation ($X \pm SD$).

Dry matter was determined according to the Association of Official Analytical Chemists [35].

Nitrogen content of samples was determined by Kjeldahl method, following the method of the AOAC (1995) [35]. Protein content of each sample was calculated by multiplying the total nitrogen content by a factor of 6.25 [36].

Ash content was determined after incineration at 550°C, during 8 hours, using a muffle furnace (NABER, Germany). It was expressed as percent of dry weight [35].

Fat content was determined by continuous extraction with a Soxhlet on samples previously dried and ground, according to the method of the AOAC. The solvent used for this analysis is hexane [35].

Fiber was determined by the adopted method described by Prosky et al. (1988) [37]. This is an enzyme-gravimetric method officially classified by AOAC (1995) [35]. The *Agave* leaves were crushed by an electric grinder for fine particles. Then, the sampling is gelatinized with a thermostable α-amylase (A-3306) and next treated with a protease (P-3910) and amyloglucosidase (A-3042) (11 500 units/mL) to hydrolyze proteins and starch.

After enzymatic hydrolysis, the residues were recovered by centrifugation and washed with distilled water (twice), alcohol 95% (twice), and acetone (once). Finally, residues are dried and weighed. Corrections are made during the determination of protein and ash. Insoluble fiber (IF) content is calculated using the following formula:

$$\%IF = (\text{Residue} - (\text{Protein} + \text{Ash})) \times 100. \quad (1)$$

After enzymatic attack, 4 volumes of 95% ethanol were added to the supernatant to precipitate inulin. The precipitate, collected by centrifugation, was washed successively with 75% ethanol, 95% ethanol, and acetone. The dried residue was weighed. Corrections are made during the determination of protein and ash. Soluble fiber (SF) content is determined from the following formula:

$$\%SF = ((\text{Residue}) - (\text{Protein} + \text{Ashes})) \times 100. \quad (2)$$

The total dietary fiber (TF) is determined as the sum of insoluble and soluble fiber:

$$\%TF = \%IF + \%SF. \quad (3)$$

Soluble sugars are firstly extracted with 15 mL of a solution of 96% ethanol with stirring at room temperature and then centrifuged at 9418 g, 4°C for 20 min. Secondly, the resulting residue was washed with 5 mL of a solution of 80% ethanol. Then, the supernatants were collected and evaporated to obtain a volume of 1 mL. Finally, it was adjusted to obtain 10 mL with distilled water [38]. The obtained solution was analyzed by the phenol-sulfuric method [39].

Polysaccharides were determined as follows: the residue obtained from soluble sugars extraction was stored for 24 hours at room temperature to evaporate the ethanol traces. Then, 10 mL of HCl (30%) was added and the mixture was incubated in a water bath at 60°C for 2 hours and then centrifuged at 9418 g, 4°C for 30 min. The supernatant was filtered through a filter paper and then adjusted to 10 mL with distilled water. The obtained solution was analyzed by the phenol-sulfuric method [39]. The assay is performed with a mixture (v/v) of 1 mL of the solutions obtained with a solution of 5% phenol. 5 mL of concentrated sulfuric acid is then added and the mixture was placed in water bath at 25–30°C for 20 min. The optical density was measured at a wavelength λ = 490 nm with a spectrophotometer (SHIMADZU mini 1240). The concentration of soluble sugars and polysaccharides is determined against a standard curve made with glucose. Total sugars were the sum of soluble sugars and polysaccharides.

The mineral constituents (Ca, Mg, Na, K) were analyzed separately, using an atomic absorption spectrophotometer (Hitachi Z6100, Japan).

The pH was measured using a pH-meter (METTLER TOLEDO MP220) at 20°C.

The levels of soluble solids of raw material, expressed as °Brix, were measured using a refractometer (Mod. DR-101, Coseta S.A., Barcelona, Spain). Both measurements were taken at 20°C.

Water activity was measured by a NOVASINA aw Sprint TH-500 Apparatus. The measurement was performed at 25°C.

2.5. Determination of Technofunctional Properties

2.5.1. Particle Size. The measurement of particle size distribution tells us about the size of *Agave* leaves powder. This particle size was measured using a sieve with a mesh size of 200 μm (Model VE 100, Retch, Germany). The fine fraction (particle size < 200 μm) was used for analysis.

2.5.2. Water Holding Capacity and Oil Holding Capacity (WHC and OHC). The method of Moure et al. (2001) was used with a slight modification. 1 g of samples was stirred in 10 mL of distilled water or corn oil and then centrifuged at 7125 g for 20 min (JOUAN CR4 22, USA). The volume of the supernatant was measured. The water-holding capacity was expressed as the number of gram of water held by 1 g of sample. The oil-holding capacity was expressed as the number of gram of oil held by 1.0 g of sample [40].

2.5.3. Emulsion Capacity (EC). The emulsion capacity was determined by a model system described by Blecker et al. (1997). Then, sunflower oil was added to 50 mL of solutions (7% w/v) and emulsified using an Ultraturax T25 (IKa, Staufen, Germany) at 15000 rpm for 10 min. During emulsification, temperature was maintained at 0°C by immersing the reaction vessel in ice bath. The sudden increase in electrical resistance showed the phase inversion point; the oil phase becomes continuous, which can be determined by electrical conductivity measurements. Emulsion capacity is expressed in g oil g^{-1} of sample [41].

2.5.4. Swelling Power. A dispersion of 200 mg of dietary soluble fiber in 10 mL of distilled water was introduced into a graduated cylinder. After 18 hours of standing at room

temperature, the amount of water retained by the fibers was determined. The swelling is the ratio between the volume of water and the test [42].

2.5.5. Solubility. The solubility of inulin extracted from the *Agave* leaves and commercial inulin was determined as follows: at 25°C. inulin was added slowly in 10 mL of water under stirring until complete dissolution and saturation. The solubility is expressed as the mass of inulin dissolved in one liter of distilled water [43].

2.5.6. Pectin-Inulin Mixed Gel Preparation. High methoxyl pectin (PHM), inulin, and mixed gels were prepared to study the effect of *Agave* inulin on gelling properties. 15% to 30% of inulin extracted from AA was used and dissolved in 50 mL of distilled water and added with sucrose until a 55°Brix of soluble solid levels. Subsequently, the PHM (4%) was added and dissolved by stirring. The pH was adjusted to 3 using a citric acid solution (10%). The obtained solution was heated to boiling with stirring until reaching a 65°Brix of soluble solids extract. Finally, the preparation was setting into cylindrical containers (3.5 cm diameter × 3 cm height). The solutions were cooled to room temperature overnight (Figure 3). Similarly, standard solutions at 4% of pectin and 20% of commercial inulin concentrations were prepared with distilled water and compared to mixed gels (the ratio PHM/inulin mixture was 4 : 20).

2.5.7. Texture Analysis. Penetration test was performed with a Texture Analyzer (Analysis LLOYD instruments, Fareham, UK) interfaced to a personal computer (Windows-based Software NEXYGEN PLOT). Constant speed penetration tests were performed directly on cylindrical containers (3 cm diameter × 3.5 cm height). All instrumental texture analyses were conducted on chilled (25°C) samples. A cylindrical probe (25 mm of diameter) was introduced for 30 mm into the samples (the speed = 40 mm/min). The prepared gels were subjected to a test initiation of chewing (Texture Profile Analysis). From the force-versus-time curves, values for the maximum force (N) were calculated as force at a distance of 15 mm (F_{max}) and a detection limit of 0.005 kg force into two times. Triplicate measures for each gel were performed. Textural parameters considered in the present study were firmness, elasticity, cohesiveness, adhesiveness, and chewiness.

2.6. Statistical Analysis. One-way analysis of variance (ANOVA) was used to determine significant differences ($P < 0.05$) between inulin-PHM gels and PHM or inulin gels. Duncan's test was used to access the differences between gels. Statistical analyses were performed on statistical analysis package STATISTICA (Release 5.0 Stat Soft Inc. Talsa, OK).

3. Results and Discussion

3.1. Physicochemical Properties of Powder and Inulin from Agave americana L. Leaves. The extracted powder and inulin from AA leaves were illustrated in Figure 2. The proximate

(1) (2)

Figure 2: *Agave americana* leaves powder (1) and inulin (2).

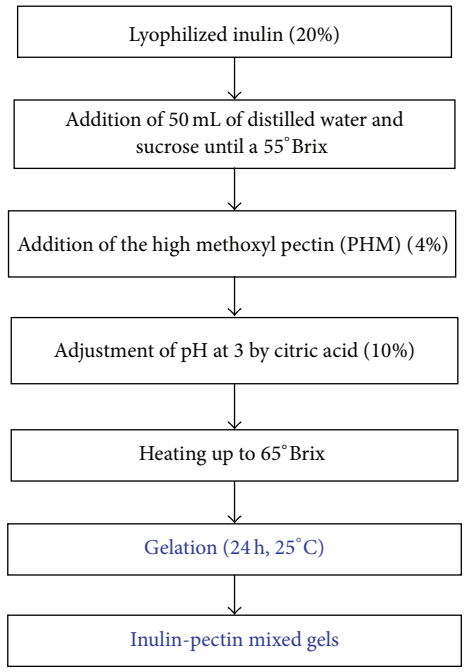

Figure 3: Diagram of inulin-pectin gels preparation.

composition of leaves powder from AA plant was presented in Table 1. Results showed a low content of the water (5.86%) which facilitates their conservation. But *Agave* is a succulent plant, and this recalls the rich succulence racket prickly when water content was approximately 92% [44].

Moreover, the total fiber content was the highest (38.40%) followed by protein content (35.33%) with a relatively low lipid (2.03%) and Ash (5.94%) levels.

The sugar fractions of *Agave* leaves were essentially formed by insoluble and soluble sugars (3.16% and 42.67% of total sugars, resp.). *Agave* leaves contained a high insoluble fiber level which confirms the appearance of the flesh filamentous leaves [45]. However, the soluble fiber fraction was lower compared to insoluble fiber fraction (9.03% against 29.37%). The soluble fraction was represented mainly by fructans [14]. The presence of this fraction confirms the choice of using leaves part of the plant for inulin extraction.

Table 1 shows the mineral composition of AA leaves powder. A predominance of potassium (1.096 mg/100 g of

Table 1: Chemical composition of *Agave americana* L. leaves powder.

Parameters	Dry matter (DM) (%)	Ash[a]	Protein[a]	Lipid[a]	Soluble sugar[a]	Insoluble sugar[a]	Soluble fibre[a]	Insoluble fibre[a]	Total fibre[a]	K	Na	Ca	Mg	pH
Lyophilised *Agave* leaves	94.14 ± 0.58	5.94 ± 0.12	35.33 ± 0.73	2.03 ± 0.06	42.67 ± 0.74	3.16 ± 0.63	9.03 ± 0.64	29.37 ± 0.59	38.40 ± 1.48	1.096 ± 0.11	0.045 ± 0.01	0.762 ± 0.13	0.092 ± 0.02	5.06 ± 0.07

[a](g/100 g DM).
[b](mg/100 g DM).

Table 2: Physicochemical properties of inulin obtained from *Agave americana* L. and commercial inulin (% DM).

Parameters	Yield	Aw	pH	Dry matter (%)	Ash (%)	Protein (%)
Agave americana Inulin	79.12 ± 0.50	0.275 ± 0.013[a]	5.53 ± 0.55[a]	92.19 ± 0.28[a]	2.89 ± 0.31[a]	3.46 ± 0.13[a]
Commercial inulin	* * *	0.282 ± 0.011[a]	5.98 ± 0.34[a]	91.67 ± 0.76[a]	1.19 ± 0.18[b]	1.58 ± 0.11[b]

Means in the same column with different letters are significantly different ($P < 0.05$).

Table 3: Functional properties of *Agave americana* L. leaves powder, inulin extracted from *Agaves americana*, and commercial inulin obtained by lyophilisation.

Parameters	Solubility at 25°C (g/L)	WHC (g of water/g of sample)	OHC (g of oil/g of sample)	SP (mL of water/g of sample)	Emulsion capacity (%)
Agave powder	* * *	14.60 ± 0.66[c]	9.87 ± 0.29[b]	15.20 ± 0.30[b]	17.17 ± 1.04[c]
Agave inulin	73.47 ± 0.14[a]	2.42 ± 0.18[b]	3.26 ± 0.59[a]	1.99 ± 0.13[a]	14.48 ± 0.23[a]
Commercial Inulin	113.68 ± 4.14[b]	1.59 ± 0.02[a]	3.47 ± 0.03[a]	1.08 ± 0.01[a]	21.42 ± 0.70[b]

Means in the same column with different letters are significantly different ($P < 0.05$).
WHC: water holding capacity, OHC: oil holding capacity, SP: swelling power.

AA) and calcium (0.762 mg/100 g of AA) was observed and low levels of sodium (0.092 mg/100 g of AA) and magnesium (0.045 mg/100 g of AA) similarly net *Aloe vera* [46].

The pH of AA powder was 5.06 presented in Table 1. This value was higher than other fibre products such as pomegranate bagasses powder coproduct 4.4 [47] or orange dietary fibre 4.06 or lemon albedo 3.96 [48, 49].

Furthermore, Table 2 presents the physicochemical properties of inulin obtained from AA and inulin extracted from commercial chicory. Both inulins had a very high dry matter (91-92%). Significant difference was observed between *Agave* inulin and commercial inulin pH (5.53 against 5.98, resp.) ($P < 0.05$). This result can be due to the differences between the two plant initial compositions.

The water activity of *Agave* inulin and commercial inulin ($P < 0.05$) was 0.275 and 0.282, respectively. The water activity and pH of *Agave* inulin and commercial inulin, both parameters highly related to product deterioration, indicate that the risk of deterioration (by microorganism, enzymes, or no enzymatic reactions) is minimal.

Inulin from AA was characterized by a higher protein and ash contents than the commercial chicory inulin (3.46% against 1.58% and 2.89% against 1.19%, resp.). This significant difference can probably be due to the difference between the laboratory and the industrial purification process and the botanical differences between the two studied plants AA and chicory.

3.2. Functional Properties. Table 3 showed the functional properties of AA powder, *Agave* inulin, and commercial inulin. The WHC of *Agave* leaves powder had the highest level compared with *Agave* inulin and commercial inulin (14.60 g of water/g of sample against 1.59–2.42 g of water/g of sample). This result can be explained by the high *Agave* fibre content (38.40%) and protein content (35.33%) [50–53]. The obtained WHC of Agave leaves powder was higher than these of the fibroprotein extracts from date seeds (4-5 g of water/g of sample) [52], the citrus fiber (10.66 g of water/g of fiber) [42], grapefruit fiber (9.77 g of water/g of fiber) [50] and orange fiber (11 g of water/g of fiber) [54].

OHC of *Agave* leaves powder was 9.87 g of oil/g of the sample. Considering this value of oil retention, the *Agave* leaves powder could be employed as like ingredient to stabilize the products rich in oil. These WHC and OHC were a function of size, shape, hydrophilic, and hydrophobic interactions and were affected by the presence of carbohydrates, lipids, and amino acid residues on the surface, since most nonpolar amino acid residues and polar groups are not hydrated in the interior [40, 52]. The particle size of *Agave* leaves powder and *Agave* inulin (particle size < 250 μm) affected technofunctional properties. Indeed, the very fine particles explained the importance of WHC and OHC increases. The high WHC and OHC of these *Agave* leaves powder and inulin suggest that it can be used as a functional ingredient to improve the sensory properties of the formulated product, to reduce syneresis, modify texture, viscosity, and reduce calories of foods.

The higher swelling property of *Agave* leaves powder might be attributed to its lower density and lager surface area among the fiber samples. *Agave* and commercial inulin have a lower swelling power than the *Agave* leaves powder (1-2 mL/g against 15.20 mL/g, resp.). It was suggested that the differences in hydration properties were a function of the physical structure of the fiber, which could be manipulated by processing history. Experimental procedures, including how sample was prepared, alter the physical structure of the fiber, which could affect the hydration properties [55]. This could explain the differences in hydration properties observed between *Agave* leaves powder, *Agave* inulin, and commercial inulin. Hydration properties determine the role of dietary fiber in regulating colonic function and also their physiological effects [56, 57].

Table 4: Effect of drying process on the technofunctional properties of inulin extracted from *Agave americana* leaves.

Parameters	WHC (g of water/g of sample)	OHC (g of oil/g of sample)	SP (mL of water/g of sample)	Emulsion capacity (%)
Lyophilisation	2.42 ± 0.18^{a}	3.26 ± 0.59^{a}	1.99 ± 0.13^{a}	14.48 ± 0.23^{a}
Drying oven ($T = 40^{\circ}C$)	1.62 ± 0.07^{b}	2.21 ± 0.12^{b}	1.5 ± 0.52^{a}	11.3 ± 0.03^{b}
Drying oven ($T = 60^{\circ}C$)	1.36 ± 0.01^{c}	1.90 ± 0.04^{c}	1.15 ± 0.68^{a}	10.49 ± 0.66^{c}

Means in the same column with different letters are significantly different ($P < 0.05$).
WHC: water holding capacity, OHC: oil holding capacity, SP: swelling power.

The solubility of *Agave* inulin was significantly lower than those of commercial inulin (73.47 ± 0.14 g/L against 113.68 ± 4.14 g/L) ($P < 0.05$). However, the solubility remained high for both. This high solubility in water probably affects the hydration properties of inulin.

The emulsion capacity (EC) is a molecule's ability to act as an agent that facilitates solubilization or the dispersion of two immiscible liquids. Emulsions are formed due to the presence of hydrophobic and hydrophilic groups of carbohydrate. The EC of the agave leaves powder was 17.17% and for *Agave* inulin was 14.48%, while the EC of the commercial inulin was 21.42%. Probably, a relationship was existed between emulsion properties and solubility of the studied fiber. This result suggests that the improvement of emulsification capacity could be due to the presence of soluble protein and fiber. M. Viuda-Martos et al. [47] reported similar result for pomegranate juice arils bagasse and pomegranate juice whole fruit bagasse.

3.3. Effect of Drying Process on the Technofunctional Properties of Inulin Extracted from AA Leaves. Table 4 presented the effect of varying the drying temperature on the technofunctional properties of the *Agave* inulin. If drying temperature increased, the various technofunctional properties decreased. For example, the WHC of lyophilized *Agave* inulin was higher than these obtained by drying oven *Agave* inulin. Therefore, it can be concluded that temperature of drying had an influence on the structure and hydrophobic characteristics of *Agave* inulin.

Significant difference was observed between the different drying processes (lyophilization, oven drying at 40°C and 60°C) concerning the functional properties except swelling power. For example, the OHC decreased with the increase of drying temperature. The lyophilized inulin OHC was 3.26 g of oil/g of sample against 2.21 g of oil/g of sample for the oven dried inulin at 40°C and 1.90 g of oil/g of sample for the oven dried inulin at 60°C. Freeze-drying has provided the most appreciated technofunctional inulin. Certainly, this process preserved the inulin structure.

3.4. Synergetic Effect of Agave Inulin on Textural Qualities of Prepared Mixed Gels. The synergetic effect of prepared *Agave* leaves inulin-PHM mixed gel on texture parameters was studied and compared to PHM gel, commercial inulin gel, and the commercial inulin-pectin mixed gel. Figure 4 and Table 5 exhibited the results of the textural analysis. The inulin showed a significant contribution to firmness, chewiness,

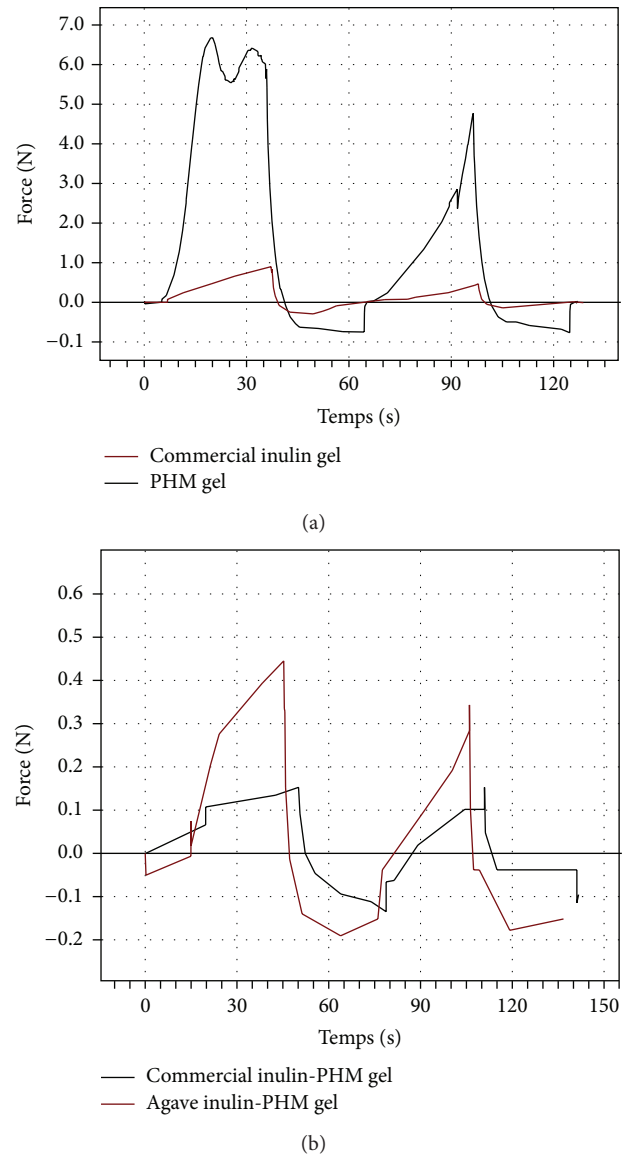

Figure 4: Texture profile of commercial inulin and PHM gels, commercial inulin-PHM, and *Agave* inulin-PHM gels.

Table 5: Texture parameters of different prepared gels with inulin and commercial high-methoxy pectin (PHM).

Parameters	Firmness (N)	Cohesiveness	Elasticity (mm)	Chewiness (N·mm)	Adhesiveness (N/mm)
Commercial Inulin	0.6836 ± 0.3068^{a}	0.3294 ± 0.0236^{a}	14.7903 ± 0.1655^{a}	4.1992 ± 0.0013^{a}	1.2318 ± 0.0583^{a}
Commercial PHM	5.7238 ± 1.3484^{b}	0.2762 ± 0.0123^{a}	14.2419 ± 0.1125^{a}	26.8461 ± 0.1425^{b}	7.4136 ± 0.0263^{b}
Commercial Inulin + Commercial PHM	0.1838 ± 0.1440^{a}	0.4138 ± 0.3784^{a}	9.2336 ± 0.3594^{b}	1.0684 ± 1.3346^{a}	0.9902 ± 0.1792^{a}
Commercial PHM + Agave Inulin	0.3554 ± 0.0550^{a}	0.3149 ± 0.0906^{a}	10.1741 ± 1.0038^{b}	1.2663 ± 0.3407^{a}	1.3051 ± 0.1636^{a}

Means in the same column with different letters are significantly different ($P < 0.05$).

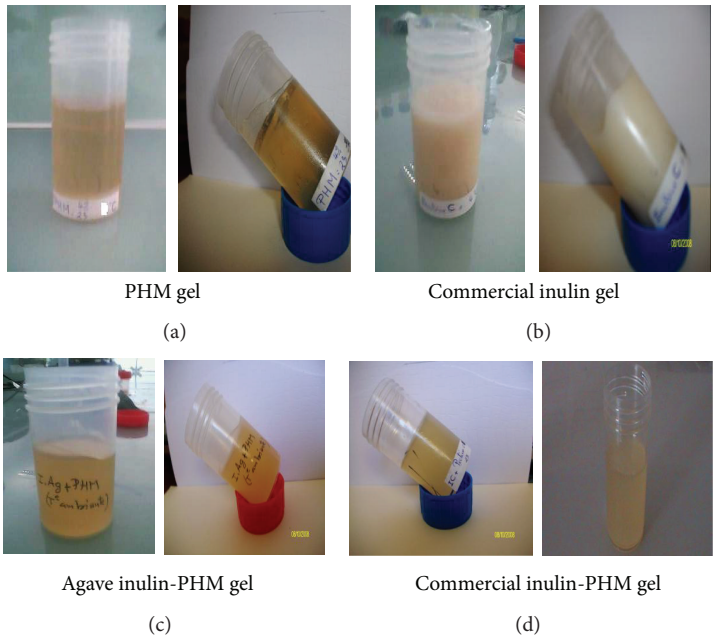

Figure 5: Different prepared gels in laboratory.

and adhesiveness of prepared inulin gels compared with commercial PHM gel.

The firmness is the force required to achieve a given deformation. No significant difference was observed between the firmness of the commercial inulin gel, the Agave inulin-PHM and the commercial inulin-PHM mixed gels. Those prepared gels were very fragile and presented a significant different firmness compared to the commercial PHM gel ($P < 0.05$). These low levels of firmness of the commercial inulin gel, the commercial inulin-PHM, and *Agave* inulin-PHM mixed gels could be explained by the presence of synergetic effect between inulin and PHM. For example, firmness of PHM-*Agave* inulin mixed gel is 0.3554 N against 5.7238 N for the PHM gel. However, firmness of PHM-*Agave* inulin mixed gel was slightly lower (0.3554 N) than these of commercial inulin gel (0.6836 N) and slightly higher than the commercial inulin-PHM mixed gel (0.1838 N). Probably, pectin reacts synergistically with *Agave* inulin which enhances the tenderness of mixed gels. This result can be explained by the presence of impurities from *Agave* inulin due to the absence of a purification step. Furthermore, firmness of the prepared gels decreased with the presence of inulin which confirms the synergy between these two hydrocolloids especially the inulin in improving the textural parameters of gels. These prepared gels were presented in Figure 5.

Adhesion was the maximum force required to remove the probe from the sample after applying a compressive force. According to the obtained results, no significant difference was shown between the adhesiveness of different prepared gels except those of PHM gel ($P < 0.05$). For example, adhesion of PHM-*Agave* inulin mixed gel was significantly lower than those of PHM gel (1.3051 N/mm against 7.4136 N/mm) ($P < 0.05$). These results confirmed the existence of synergy between principally inulin and PHM.

Cohesiveness was the ratio of the area under the curve of the second compression to the area under the curve of the first compression [58]. Table 5 indicates that the cohesion was very low in different gels. The cohesiveness levels, ranging between 0.2762 and 0.4138, were not changing significantly for the mixed gels.

Elasticity was the height at which the sample returns to its original size after compression [59]. Significant difference was shown between elasticity of commercial inulin and PHM gels and the mixed gels (*Agave* inulin-PHM and commercial inulin-PHM gels). However, the *Agave* inulin-PHM or commercial inulin-PHM mixed gels were slightly lower compared with PHM and commercial inulin gels (9-10 mm against 14 mm, resp.). These results can be explained by the synergetic effect between pectin and inulin gels.

Furthermore, these results could be explained in the fact that the *Agave* inulin contains proteins, sugars, and fibers other than inulin in low proportions. For example, the protein fraction present in the *Agave* inulin was about 3.46%; thus more residues have probably a role in gelation such as the S-S bridge. They are involved in establishing a gel network. The *Agave* inulin-PHM gel had an appreciated texture more than the commercial inulin-PHM gel and gives importance to the *Agave* inulin to play the role of a texturing in various food formulations. Yet the saturation of synergy between inulin, protein, and pectin affected the general appearance of the mixed gels and revealed the higher affinity of compounds for the pectin matrix. Similar phenomena were reported between k-carrageenan and hydrocolloid from leaves of *Corchorus olitorius* [60].

Moreover, the presence of inulin can probably cause local disruptions of the pectin gel structure and at the same time reduces the freedom of polymeric chains of pectin for searching for an ordered binding. The *Agave* inulin changed the properties of the matrix resulting in a more nonpolar matrix. This is indicated by a larger retention of the more hydrophobic compounds than the less hydrophobic compounds in the more rigid gels [61].

When solutions of two biopolymers were mixed, interactions between their chains depend on the balance between the enthalpy and the entropy changes on mixing, being, therefore, either favorable (association) or unfavorable (segregation) [62]. Almost all biopolymer mixtures exhibit segregate interactions, unless there is an electrostatic drive to association. These usually result in phase separated networks where the components tend to exclude each other from their domains [63].

4. Conclusion

The present paper reported the basic chemical and physicochemical properties of inulin from leaves of AA obtained by water extraction. Results indicated the potentiality to valorize *Agave americana* L. leaves of Tunisia, especially inulin fraction. For gelling properties, it has revealed that PHM-*Agave* inulin gel exhibited lower firmness due to the synergy between *Agave* inulin and pectin in relation to gel strength. This synergy implies that inulin could not only be an alternative to pectin in many applications but may introduce new functions to inulin. Thus AA is an interesting source of inulin though further investigation should be done in order to fully explore the potential of this studied hydrocolloid.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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