Structural polysaccharides in xoconostle (*Opuntia matudae*) fruits with different ripening stages

Rosario Álvarez Armenta and Cecilia Beatriz Peña-Valdivia*

Botánica, Colegio de Postgraduados, Campus Montecillo. Km 35.5 carretera México-Texcoco. Montecillo, Texcoco, 56230, México.

*Author for correspondence, E-mail: cecilia@colpos.mx

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Abstract

The objective of this research was to isolate, purify and quantify the content of mucilage, pectins, hemicelluloses and cellulose of the acidic cactus fruits of *Opuntia matudae* with commercial maturity. Fruits were collected in an orchard for commercial production of cactus pear fruit and pads in San Martin de Las Pirámides, Mexico. Fruits were grouped according to the receptacle depth, fruit dimensions and proportion of structures. The structural polysaccharides of the dehydrated and finely crushed skin (edible portion) fruits, were sequentially extracted with water and aqueous solutions of ammonium oxalate and potassium hydroxide, precipitated with ethanol, purified by dialyzing or watery washing and gravimetrically quantified after being lyophilized. Although, fruits were harvested with significantly homogenous size, and identified by the farmer like adequate for commercialization (with equatorial and polar diameters homogenous between the fruits, 51.7 mm, 45.2 mm respectively), they were grouped in three depending on receptacle depth (between 3.8 and 6.9 mm) and other parameters, like total wet biomass (between 64 and 81 g/fruit) and dry biomass (between 1.9 and 33.3 g/fruit), skin thickness (between 11.3 and 12.7 mm) and total number of seeds (120 to 205 abortive plus normal seeds/fruit). In addition, also it was confirmed that fruit ripeness of *O. matudae* is inversely related to the depth of receptacle. Mucilage, pectin and cellulose represented a significantly higher amount in the ripe fruits (7.5, 8.0 and 15.4%, respectively) than in the unripe (1.8, 2.5 and 10.0%, respectively); whereas the hemicelluloses content in all three classified ripe states was significantly similar (in average 3.2 and 1.5 % of loosely and tightly bound hemicelluloses). The results indicate that xoconostle fruits are rich in soluble (7.8 to 18.6%) and insoluble (11.6 to 16.5%) dietary fiber, and the type of polysaccharides varies in dependence of fruit ripening.

Key words: dietary fiber, soluble fiber, insoluble fiber, mucilage, pectin, hemicelluloses, cellulose.

Resumen

El objetivo de esta investigación fue aislar, purificar y cuantificar el contenido de mucílago, pectinas, hemicelulosas y celulosa de los frutos de *Opuntia matudae* con madurez comercial. Los frutos fueron recolectados en un huerto para producción comercial de tuna y nopal de San Martín de las Pirámides, México. Los frutos fueron clasificados con la profundidad del receptáculo, se determinaron las dimensiones de los frutos y proporción de sus estructuras. Los polisacáridos estructurales de la cáscara (tejido comestible) de los frutos, deshidratada y triturada finamente, fueron extraídos en secuencia con agua y soluciones acuosas de oxalato de amonio e hidróxido de potasio, precipitados con etanol, purificados mediante diálisis o lavado acuoso y cuantificados gravimétricamente después de ser liofilizados. Aunque los frutos fueron cosechados con tamaño medio significativamente homogéneo, e identificado por la productora como el adecuado para la comercialización (con diámetros ecuatorial, 51.7 mm, y polar, 45.2 mm, estadísticamente iguales entre los frutos), se formaron tres grupos con madurez diferente en dependencia de la profundidad del receptáculo (entre 0.6 y 6.9 mm) y otros parámetros, como la biomasa total húmeda (entre 64 y 81 g/fruto) y seca (entre 1.9 y 3.3 g/fruto), grosor de la cáscara (11.3 a 12.7 mm) y número total de semillas (120 a 205 abortivas y normales/por fruto) fueron significativamente diferentes entre los grupos. Además, esto también confirmó que la madurez de los frutos de *O. matudae* está relacionada inversamente con la profundidad del receptáculo. El contenido de mucílago, pectinas y celulosa representó una cantidad significativamente superior en los frutos con mayor madurez (7.5, 8.0 y 15.4%, respectivamente) respecto a los menos maduros (1.8, 2.5 y 10.0%, respectivamente); mientras que el contenido de hemicelulosas fue significativamente similar en los tres estados de madurez identificados (en promedio 3.2 y 1.5% de hemicelulosa débilmente y fuertemente unida a la celulosa). Los resultados indican que los frutos de xoconostle son un alimento rico en fibra alimentaria soluble (7.8 a 18.6%) e insoluble (11.6 a 16.5%), y el tipo de polisacáridos que los conforman varían en dependencia de la madurez del fruto.

Palabras clave: fibra alimentaria, fibra soluble, fibra insoluble, mucílago, pectinas, hemicelulosa, celulosa.

Introduction

Medicinal plants have been used with therapeutic aims in the Mexican herbalism (a traditional Medicine or folk medical practice based on the use of plants and plant extracts; also known as botanical medicine, medical herbal, herbal medicine, herbology, and phytotherapy) since pre-Columbian times, and these plants have continuously been used until now, and seems that every day they acquires greater scientific importance, because the formal investigation of their effects on human health care. On the matter, almost 500 vegetal species has been documented in Mexico, for the treatment of diabetes mellitus. According to Andrade-Cetto and Heinrich (2005) the best represented families in medicinal plant research, by number of genus, are the Asteraceae (47), Fabaceae (27), Cactaceae (16), Solanaceae and Euphorbiaceae (10) and Laminaceae (9). Cactaceae includes the genera *Opuntia* and *Lophocereus* which have been widely studied and the results that endorse these genera because popular uses like antidiabetic agents have been published (Bravo and Sanchez, 1991; Yeh *et al*., 2003).

Alarcon-Aguilar *et al*. (2003) assured that the Ethnobotanic information which documents the use of *Opuntia* for diabetes treatment in Mexico dates from the decade of the 1970s. The potential use for *Opuntia* plants in Mexico is ample, since 83 Mexican species have been registered (Guzmán *et al*., 2003). Alarcon-Aguilar *et al*. (2003) indicated that among the anti-diabetics plants most frequently used are *O. ficus-indica* and *O. streptacantha* plants; and it seems that the fruits known like “xoconostle” (name of the prickly acid or sour cactus pear fruit), corresponding to *O. joconostle*, *O. duranguensis*, *O. leucotricha* y *O. matudae* are significantly more important (Cassiana, 2007). Xoconostle has low pulp content, and heavy, acid edible skin (Reyes-Agüero *et al*., 2005; Scheinvar, 1999). Xoconostle fruits are consumed as much for therapeutic aims as in the preparation of foods, treats, drinks and other products (García-Pedraza *et al*., 2005a).

The biological effects on human health of *Opuntia* spp. pads (mature stems), “nopalitos” (young cladodes), fruits (“tunas”) and flowers have been documented. These plant tissue could be consumed crude, roasted or cooked, as well as its juice for cardiovascular and oxidation protection, as antiulcerant, and hepatoprotector; and positive effects on acidosis, hyperglycemy, gastritis, hyperlipidemia, fatigue and dyspnoe, have also been described; besides the *Opuntia* spp. tissues are used to improve digestion and enhance the general detoxification processes, also they are applied to treat rheumatic disorders, erythemas and chronic skin infections and many others illness (Alarcon-Aguilar *et al*., 2003; Bwititi *et al*., 2000; Cassiana, 2007; Fernandez-Harp *et al*., 1984; Fernández *et al*., 1992 and 1994; Frati *et al*., 1990; Ibanez-Camacho *et al*., 1983; Livrea and Tesoriere, 2006; Perfumi and Tacconi, 1996; Wolfram *et al*., 2002).

The chemical compounds of the *Opuntia* spp. tissue that cause such beneficial effects are only partially known; some of them are dietary complex carbohydrates (polysaccharides), like mucilage, pectins, and some other compounds like vitamins and polyphenols (Galati *et al*., 2002; Wolfram *et al*.; 2002). In relation to the physiological effects of complex molecules mainly in humans, it has been documented that dietary fiber of a given composition, or some fiber components, are useful to controlling body weight, diabetes and arteriosclerosis, and also prevent or reduce the incidence of cancer, constipation, hemorrhoids, cardiovascular diseases, accelerate the healing processes, and many others (Cummings *et al*., 2004; Wolfram *et al*., 2002). The insoluble polysaccharides (conformed by tightly bound hemicelluloses and cellulose) increase the volume of the alimentary bolus and the passage of the food throughout the digestive tract (Hsu *et al*., 2004); while, the soluble fiber (mucilage, pectins and loosely bound hemicelluloses) increases the viscosity of the intestinal content and regulates the concentration of glucose and cholesterol in blood (Binns, 2003; Cummings *et al.*, 2004; Englyst and Englyst, 2005; Figuerola *et al.*, 2005; Sáenz, 2004 and 2006).It has been demonstrated that nopalitos (*Opuntia* spp.) are a natural source of a variety of polysaccharides (mucilage, pectins, hemicelluloses and cellulose), and that the content of each class of polysaccharide is also variable but, remarkably abundant depending on the specie, variant (cultivar or wild), and growth conditions (temperature, humidity, soil type, etc); besides, the process of blanche and cook of nopalitos modified the proportion of some classes of polysaccharides (Camacho *et al*., 2007; Peña-Valdivia and Sánchez-Urdaneta, 2006). A similar variability of polysaccharide composition has been documented in the pulp of ripe *O. ficus-indica* fruits, but the proportion found was less than a tenth comparing with that of nopalitos (Peña-Valdivia and Sánchez-Urdaneta, 2004 and 2006); in contrast, similar information in xoconostle is not available, as far as we are concern.

Xoconostle (*Opuntia* spp.) is a species with acid fruits, which growths in arid and semi-arid climates, in wild "nopaleras" and some commercial plantations of the central plateau of Mexico (García-Pedraza *et al.,* 2005b). One of the producing and consuming regions of xoconostle in Mexico includes the municipalities of the east of the State of Mexico, like Texcoco and San Martin de las Pirámides (Cano *et al*., 1999; Scheinvar, 1999). *Opuntia oligacantha* and *O. matudae* are cultivated in this region; *O. oligacantha*'s fruits are called "chivo" and contrast with the *O. matudae*'s fruits, called "cuaresmeños", because these are spineless and can remained attached to the plant from one year to another without mechanical damaged; this is the most popular specie cultivated in the zone and reaches a price in the market greater than *O. oligacantha* (Cano *et al*., 1999). Xoconostle fruit is a spherical, cylindrical or piriform berry, and exhibits an apical depression or receptacle, called navel ("ombligo"), contains a very small proportion of pulp, and thick-acid-freshly pericarp (fruit wall consisting of two layers: exocarp and mesocarp, or "skin" or "shell" of the fruit). Given the high potential of use and consumption of xoconostle fruits and the lack of information about its detailed chemical composition, it was developed the present research, with the objective to isolate, purify and quantify the structural polysaccharides of *O. matudae* fruits at harvest maturity.

Materials and methods

Plant material

Xoconostle (*O. matudae*) fruits were recollected in a production zone of white (sweet) "tuna" and xoconostle in San Martin de Las Pirámides, Mexico, at 19°41' N and 98°49' W, and 2300 m above sea level (Cano *et al*., 1999).

Methods

One hundred ripe fruits were harvested by the producer Mrs. Carmen Ramirez Rosales, who use colour and size of the fruit as maturity indices for harvest it. They were harvested at 7-9 hours, on 20 April, 2008, of eight plants of a commercial plantation. The fruits were packed in cardboard boxes and transferred to the laboratory of Plant Biophysics, at the Botany Department in the Colegio de Postgraduados, Texcoco, Mexico. Then, fruits were manually selected based on visual inspection and fruit with mechanical damage were removed. Since the apical depression among fruits was heterogeneous, it was decided to classify them using the criteria of apical depression included in the official norm for some Opuntia species, *i.e. O. ficus indica, O. streptachanthae* and *O. lindheimeiri* (CODEX Alimentarius, 2008; Secretaría de Comercio y Fomento Industrial, 2008). Fruits were selected by visual examination and grouped in three, each group included 20 fruits with high, medium and low apical depression (receptacle depth) each one, respectively.

After that, the apical depression, the polar and the equatorial diameter of each intact fruits it was measured with a vernier. The fruits were cut by half and the skin thickness was registered with a vernier. The fresh biomass of the skin and seeds of each fruit was determined in an analytical balance (0.0001 g precision; Scientech, USA), later the fruit tissues were freeze and dehydrated by lyophilizathion (0.2 mBar and -54 C; LABCONCO FreeZone, USA) and the dry tissue biomass was obtained in analytical balance. Abortive and well formed seeds were counted.

The dehydrated skin was crushed in a mortar until obtaining fine flour that was used to quantify the content of structural polysaccharides (i.e. mucilage, pectins, hemicelluloses and cellulose). The method used for polysaccharides extraction, purification and quantification was described and used for raw and cooked nopalito and tuna, by Peña-Valdivia and Sánchez-Urdaneta (2004, 2006) and it was an adaptation of the methodology developed for the quantification of the structural polysaccharides of common bean seeds by Peña-Valdivia and Ortega-Delgado (1984 and 1986). The methodology includes the extraction in sequence of polysaccharides with hot water an aqueous solution of ammonium oxalate and potassium hydroxide, precipitation with ethanol, purification by washing with water and dialysis against water and gravimetric quantification after being freeze drying.

Mucilage was extracted from 300 mg of xoconostle flour, with 5 ml of distilled water and in a boiling water bath, during 30 min; the solid phase (vegetal remainder) was separated from the supernatant by centrifugation (1400 x *g*, during 5 min). The remainder tissue, without mucilage, was added with a quelant (0.5% ammonium oxalate in water w:v) and heated in a boiling water bath, during 30 min for pectin solubilization; again, the solid phase (vegetal remainder) was separated from the supernatant by centrifugation (1400 x *g*, during 5 min). The loosely bound and tightly bound hemicelluloses were extracted in sequence with 5 % and 24 % aqueous KOH (w:v), respectively, from the remainder material without mucilage and pectins; in each case, after hemicelluloses solubilization in respective KOH solution, during 12 h at laboratory temperature (23±3 ºC) and with constant agitation (826 x g) in an orbital agitator (Shaker, USA), the solid phase was separated from the supernatant by centrifugation

(1400 x *g*, during 5 min). The final remainder, after extracting mucilage, pectins and hemicelluloses, represented the crude cellulose, which was alternating washed with water and ethanol, until the last watery washing reached pH 7. In order to assure the exhaustive extraction of each type of polysaccharide, the mucilage, pectins, loosely bound and tightly bound hemicelluloses extraction was three times repeated in the same sample, and in the case of the hemicelluloses each extraction with KOH extended by 12 hours. The three supernatant of each polysaccharide extraction (water, ammonium oxalate, 5 % KOH and 20 % KOH) were mixed and each kind of polysaccharide was precipitated by addition of four volumes of cold ethanol (maintained previously in the freezer to -20 ºC). The hemicelluloses precipitation was complemented with the addition of 4-5 drops of concentrated HCl. In order to assure the total polysaccharides precipitation in each respective solution, after adding the ethanol the containers were maintained during 8-12 h in a refrigerator (5±2 ºC).

After that time, each class of polysaccharide was recovered, as precipitated, by centrifugation (1400 x *g*, during 5 min) of the cooled suspensions, and after eliminating the supernatant. The crude polysaccharides, thus obtained, were purified by dialysis against water, during 72 h; for this, polysaccharides were placed in tubular membrane for dialysis (Spectra of 1.8 mm of thickness, U.S.A. 15 kD cut off), the cylindrical packages with the polysaccharides were placed in containers with distilled water (renewed every 4 hours), and constant agitation (826 x *g* in orbital agitator PRO VSOS-4P, U.S.A.). After dialysis, the polysaccharides were transferred to "Ependorf" tubes, congealed, dehydrated by freeze drying and weighted in an analytical balance. The results were expressed as percentage of polysaccharide in dry tissue.

A completely random experimental model was used; it included three treatments (stages of maturity of the fruits), a fruit as experimental unit and 20 repetitions for the evaluation of dimensions, biomass and depth of receptacle, and six repetitions for polysaccharides quantification. An ANOVA and multiple mean comparisons by Tukey's test, with the statistical SAS software, for personal computer were carried out. Graphical representation of data was made with the SigmaPlot of Jandel Scientific (version 9) software, for personal computer.

Results and discussion

Fruit maturity

The depth of the receptacle allowed distinguishing the fruit ripening stage. The well ripe fruits showed a practically flat receptacle, whereas in the less ripe fruits the receptacle was (3.8±0.24 and 6.9±0.23 mm) 11.5 times more depressed (Figure 1A). Nevertheless, the fruits size (equatorial and polar diameters) was similar between all three groups, independently of ripening (Figure 1B). In agreement with the criterion of receptacle depth (CODEX Alimentarius, 2008; Secretaría de Comercio y Fomento Industrial, 2008), the total wet biomass (skin and seeds) and dray biomass of the fruits increased with ripening, and the totally ripped fruits presented significantly higher, wet and dry, total biomass (81.6±2.50 and 3.3±0.71 g/fruit, respectively) among all three groups (Figure 1C and 1D). Thus, the totally ripened fruits weighed 7 and 19 g more than those less ripped (Figure 1C).

The ripening differences were also evident in the fruit skin thickness (Figure 2A) and the number of seeds (Figure 2B). In the first case, the fruits of the three states of ripening showed a gradient of skin thickness (from 11.32±0.30 to 12.68±0.26); nevertheless, the mean comparison showed only two groups, something similar was observed with the number of normal and abortive seeds.

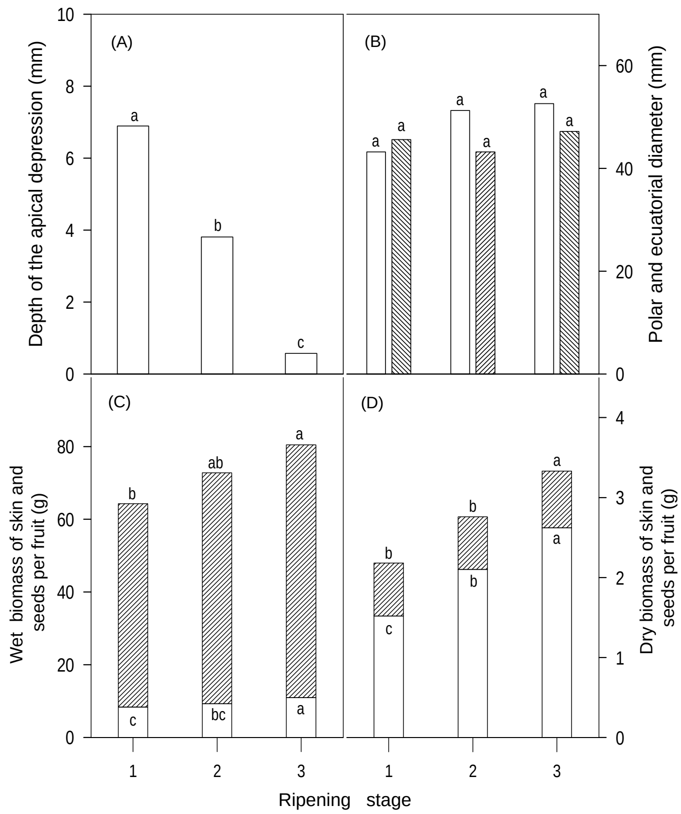

Figure 1.Size and weight of xoconostle (*Opuntia matudae*) fruits with different level of ripeness, harvested in San Martín de Las Pirámides, Estado de México, México, during spring of 2008. (A) Depth of the apical depression, (B) polar diameter (open columns) and equatorial diameter (dark pattern columns), (C) wet biomass of the seeds (open section in columns) and skin (dark pattern section in columns) per fruit, and (D) dry biomass of the seeds (open section in columns) and the skin (dark pattern section in columns). Same letters inside or over the columns indicate statistical similarity ($p \leq 0.05$) of each parameter between the stages of ripening (n = 20).

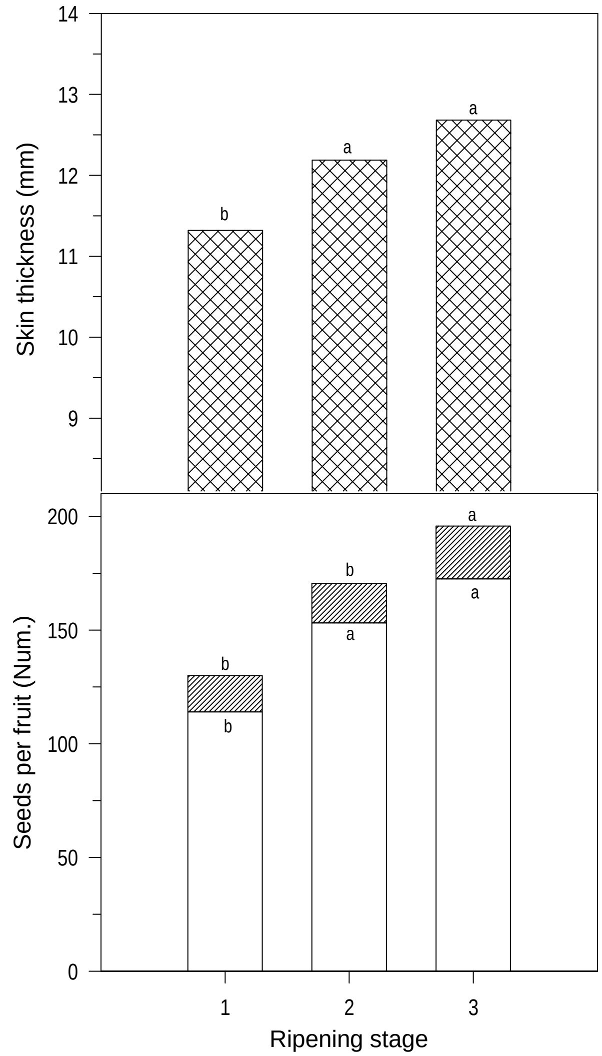

Figure 2.Skin thickness (A) and seeds per fruit (B; well formed seeds: open section in columns, and aborted seeds: dark pattern section in columns) in xoconostle (*Opuntia matudae*) fruits with different level of ripeness, harvested in San Martín de Las Pirámides, Estado de México, México, during the spring of 2008. Mean values (n = 20) with the same letters, inside or over the columns, for each parameter, are similar between ripeness levels, according to Tukey's multiple comparison test ($p \leq 0.05$).

All these results show that although the fruit were harvested with significantly similar mean size (45.20 mm/51.73 mm), and identified by the farmer as the adequate size for commercialization, some ripening parameters, like total wet and dry biomass per fruit, skin thickness and seeds proportion, were statistically different among the groups identified. In addition, the above parameters also confirm that fruit ripening seems to follow an inverse relationship with the receptacle depth. This characteristic has been included as quality trait for species like *O. ficus indica, O. streptachanthae* and *O. lindheimeiri* (CODEX Alimentarius, 2008; Secretaría de Comercio y Fomento Industrial, 2008), but it has been no reported in xoconostle.

Structural polysaccharides

The proportion of the structural polysaccharides was significantly different between fruits harvested at different ripening stages (Figures 3 and 4). Mucilage and pectins represented the biggest proportions (between three and four times) in the more ripening fruits, with respect to less ripe fruits. In contrast, the loosely bound hemicelluloses (so called for being extracted with diluted KOH in this study) represented significantly equal amounts between the fruits with different stage of ripening. It is interesting to note that in contrast with mucilage and pectins, the content of loosely bound hemicelluloses represented a significantly very low proportion (3.1%) of dry skin weight in the totally ripe fruits (Figure 3).

Similarly to the loosely bound hemicelluloses, the tightly bound hemicelluloses (so called because they are tightly bound to the cellulose fibrils and should be extracted with concentrated KOH solution) reached relatively low contents (< 2%) in all three fruit groups; beside, this kind of polysaccharides represented significantly similar proportion in dry xoconostle fruit independently of fruit stage of ripening (Figures 3 and 4).

The cellulose content contrasted with the other structural polysaccharides, like mucilage, pectins and both loosely and tightly bound hemicelluloses, since cellulose got the highest polysaccharides concentration, up to 15.40±0.94% of the total dry biomass of the fruit skin. Results show that, like mucilage and pectins, the content of cellulose in the skin increased as ripening of the fruit increases, reaching de highest concentrations among all type of polysaccharides evaluated, and even the lesser ripening fruits contained relatively high content of cellulose (between 10.08±0.55 and 14.10±0.93 (Figure 4).

These results also indicate that with the ripening of xoconostle fruits there is a increase mainly of the content of mucilage and pectins, and cellulose in smaller proportion, whereas the content of both loosely and tightly hemicelluloses remains stable and in relatively low proportion (Figures 3 and 4).

The high content of mucilage in the xoconostle fruits contrasted with the *Opuntia ficus-indica* sweet fruits (prickly pear or tuna), since in sweet tuna the mucilage represents a relatively low proportion of the total structural polysaccharides. On the matter, Peña-Valdivia and Sánchez-Urdaneta (2006) determined that mucilage amounted 1 % in the dry pulp of the sweet fruits of the cv. Solferino, independently of the fruit ripening, and in other cultivars like Copena V and Moradaza the content of mucilage in the pulp of totally ripe fruits was significantly smaller (0.45%).

It was noticeable that the content of mucilage (7.5±0.56%), pectins (8.0±1.06) and loosely bound hemicelluloses (3.0±0.81%) in the skin of totally ripe xoconostles were similar to that found in nopalitos of some of the 13 variants of *Opuntia* spp. studied by Camacho *et al*. (2007) and Peña-Valdivia and Sánchez-Urdaneta (2004, 2006); in these studies mucilage amounted between 3 and 9%, whereas pectins and loosely bound hemicelluloses represented between 5.3 and 18.0%, and 2.7 and 10.7% of dry biomass of nopalito, respectively. In contrast, pectin and loosely bounded hemicelluloses in sweet tuna fruits of the cultivars Moradaza and Solferino (*Opuntias ficus-indica*) represented only between 0.7 and 1.6, and 1.6 and 2.1%, respectively, of the dry pulp (Peña-Valdivia and Sánchez-Urdaneta, 2004, 2006).

Like in xoconostle, the content of tightly bound hemicelluloses represented a low proportion (0.6 and 1.9%) of the total polysaccharides in the pulp of sweet tunas (Peña-Valdivia and Sánchez-Urdaneta, 2004) and nopalitos (from 2.0 to 4.7%) of 13 variants of *Opuntia* spp. (Camacho *et al*., 2007; Peña-Valdivia and Sánchez-Urdaneta, 2004). The proportion of cellulose in the xoconostle skin also is in the interval (10 to 15 %) of that in nopalitos of some cultivars, like Atlixco, Blanco Espinoso, Copena F1, Copeva V1, Jade, Milpa Alta, Polotitlan, Texas, Tovarito and Toluca, evaluated by Camacho *et al*. (2007), Nefzaoui and Ben (2001) and Peña-Valdivia and Sánchez-Urdaneta (2004), and it is several times higher than in the pulp of tuna (1 to 2%) (Peña-Valdivia and Sánchez-Urdaneta, 2004).

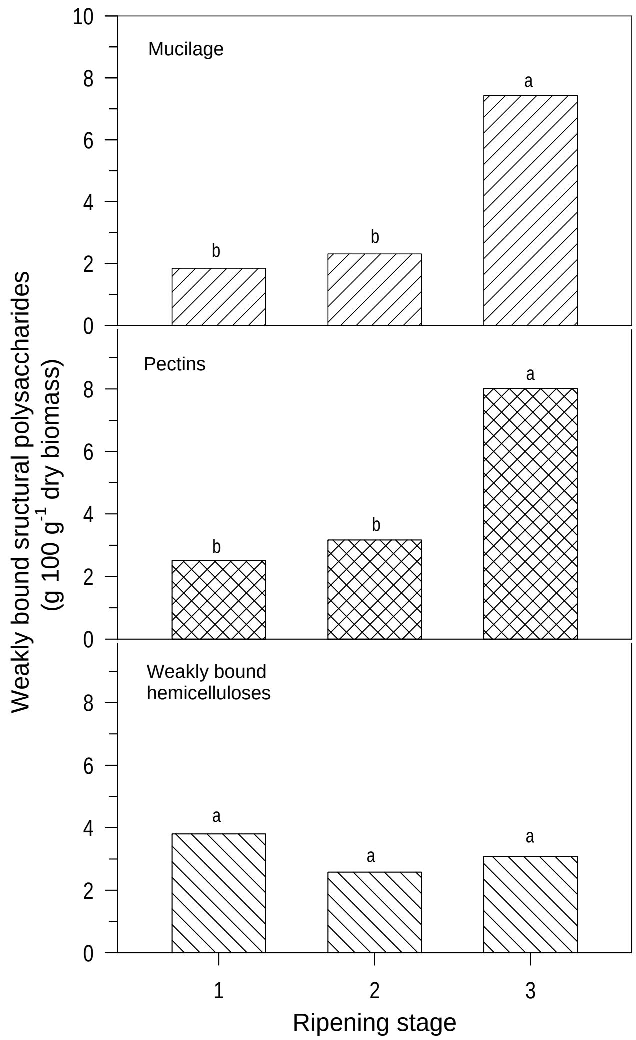

Figure 3.Content of mucilage, pectin and loosely bound hemicelluloses in xoconostle (*Opuntia matudae*) fruits with different level of ripeness and harvested in San Martín de Las Pirámides, Estado de México, México, during the spring of 2008. Mean values (n = 6) with the same letters over the columns, for each type of polysaccharide, are similar between ripeness levels, according to Tukey's multiple comparison test ($p \leq 0.05$).

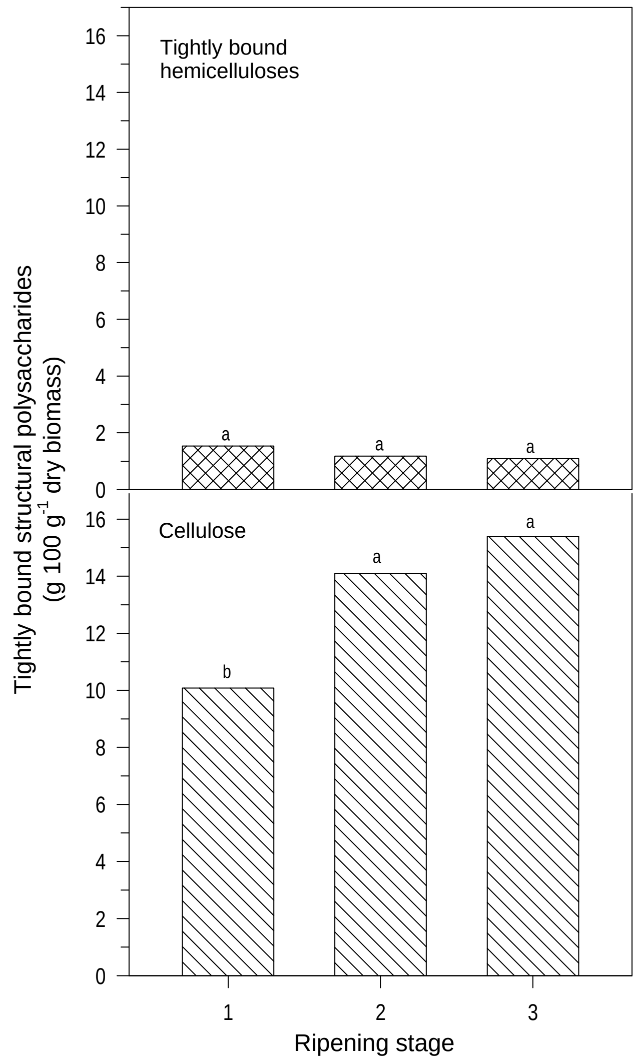

Figure 4.Content of tightly bound hemicelluloses and cellulous in xoconostle (*Opuntia matudae*) with different level of ripeness, and collected in San Martín de Las Pirámides, Estado de México, México, during the spring of 2008. Mean values ($n = 6$) with the same letters over the columns, for each type of polysaccharide, are similar between ripeness levels, according to Tukey's multiple comparison test ($p \leq 0.05$).

Dietary fiber

The dietary fiber is mainly integrated by the polysaccharides from the cellular walls of plants; the polysaccharide composition is a variable mixture of pectins, hemicelluloses etc., and, in addition it includes other structural components, like lignin, proteins and some ions (Pszczola, 2006). The dietary fiber is classified as soluble and insoluble, depending on its solubility properties and physical-chemistry characteristics; although, the separation among them is no totally clear, because it depends on the conditions of extraction (Hsu *et al*., 2004; Peña-Valdivia and Sánchez-Urdaneta, 2004 and 2006). Therefore, soluble fiber includes mucilages, pectins and some hemicelluloses, known as gums; whereas, polysaccharides conforming the insoluble fiber includes another type of hemicelluloses (those classified like tightly bound), cellulose, and other non-polysaccharide components, like lignin (Pszczola, 2006).

In the xoconostle fruits it was evident the diversity and heterogeneity of dietary fiber polysaccharides depending on fruit ripening (Figures 2 to 4). Less ripe fruit contained relatively low proportions of soluble fiber (7.74±1.54 %), whereas most ripened fruit contained significantly greater proportions of this group of polysaccharides, it amounted near to three folds than the immature fruits (18.53±1.63 %). In contrast, the insoluble fiber content, that in this study includes the tightly bond hemicelluloses and cellulose, was abundant (between 11.61±0.34 and 16.5±0.95 %) in all three ripening condition, but significantly smaller in less rip fruits (Figure 5). It should be indicate that lignin, which is no a polysaccharide, is one of the less desirable components of the insoluble fiber, because its anti-physiological effects (García and Peña, 1995); although, it could be present in xoconostle, in the present study was no quantified. On this matter, Peña-Valdivia and Sánchez-Urdaneta (2004) demonstrated the lignin absence in the pulp of sweet fruits of two cultivars of *O. ficus-indica* and in nopalitos of 13 variants of *Opuntia* spp. Similarly, Lamghariel *et al*. (1998) analyzed the total fiber composition in *Opuntia ficus-indica* fruit pulp, and determined that in the 20.5% of total fiber only 0.01% represented lignin.

The physiological response of humans and animals in laboratory to the structural polysaccharides intake depends on the amount and source of food fiber (Cummings *et al.*, 2004; Englyst and Englyst, 2005; Figuerola *et al.*, 2005). It has been reported that the soluble fiber has hypolipidemic, hypoglycemic and hypocholesterolemic action, beside it increases the viscosity of the gastric juice in the stomach, reduces the absorption of nutrients and is an option for the treatment of the obesity (Binns, 2003; Cummings *et al.*, 2004; Englyst and Englyst, 2005; Figuerola *et al.*, 2005; Sáenz, 2004 and 2006). The biological effects of insoluble fiber in humans has been also documented; it includes the regulation of intestinal function, movement bulk through the intestines and control and balance the pH (acidity) in the intestines, this prevent the incidence of gastrointestinal diseases, cancer of colon and intestinal constipation (Zambrano *et al*., 1998). Besides, up to now the biological effect of some of the complex polysaccharides from the unavailable fiber has been experimentally demonstrated. The group of pectins are effective in diminishing the cholesterol level on hyperlipidemic animals and humans, diminish the carbohydrate absorption and the postprandial increase in sanguineous glucose and insulin in the serum of patients with diabetes type II (Binns, 2003; Cummings *et al.*, 2004; Englyst and Englyst, 2005; Figuerola *et al.*, 2005; Goycoolea and Cárdenas, 2003; Sáenz, 2004 and 2006; Yeh *et al*., 2003). Experimentally it has been demonstrated in animals that pectins isolated from *Opuntia* diminished the level of low density lipoproteins, hepatic free and sterified cholesterol, and the relative activity of hepatic enzymes (Fernandez *et al.* 1990; Fernandez *et al.* 1994); in addition, they have antiinflammatory effect (Galati *et al.* 2003). Alarcón *et al*. (2003) indicated that the species of *Opuntia* which are more frequently used to incorporate fiber to foods are *O. ficus-indica* y *O. streptacantha*. Similarly, Peña-Valdivia and Sánchez-Urdaneta (2004) indicated that *O. ficus-indica* is the most popular because this specie includes a great number of cultivars and also there are great amount of species of *Opuntia* that are unknown and consequently are low demanded. The results of this study allow affirming that the mature fruits of *O. matudae* (Figure 6 to 9) remarkably represent an abundant fiber source (> 36%) with similar proportions of soluble (18.5%) and insoluble (17.5) fiber.

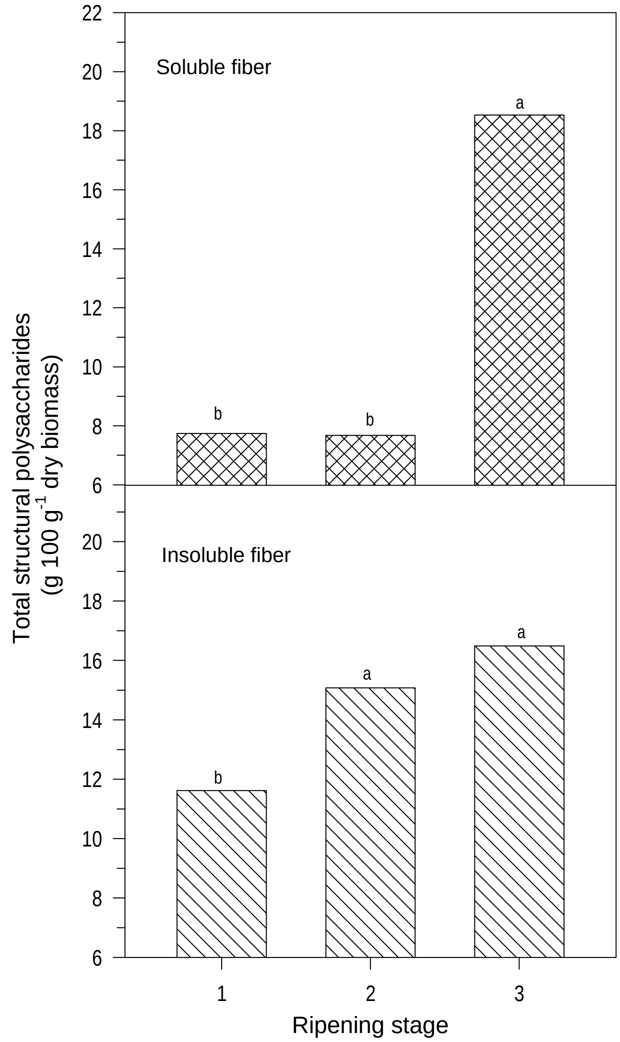

Figure 5.Content of soluble and insoluble fiber in xoconostle (*Opuntia matudae*) fruits with different level of ripeness, and harvested in San Martín de Las Pirámides, Estado de México, México, during the spring of 2008. Mean values (n = 6) with the same letters over the bars, for each type of fiber, are similar between ripeness levels, according to Tukey's multiple comparison test ($p \leq 0.05$).

Figure 6. View of overall plant morphology of *Opuntia matudae* in San Martín de Las Pirámides, Estado de México, México.

Figure 7. View of fruit and cladode of *Opuntia matudae* on the plant in San Martín de Las Pirámides, Estado de México, México.

Figure 8. Close up of the areoles on the cladode of *Opuntia matudae*.

Figure 9. Internal view of fruit of xoconostle (*Opuntia matudae*).

Conclusions

The fruits of xoconostle (*O. matudae*) at harvest for commercialization are homogenous in dimensions (*i.e.* polar and equatorial diameter), but the ripening is inversely related to the depth of the receptacle. Some morphologic parameters, like the thickness of the skin, total fruit biomass and number of seeds by fruit can be used to recognize the real stage of xoconostle ripening. The xoconostle fruits are rich in soluble and insoluble dietary fiber; although, the proportion and composition of its dietary fiber is variable in dependence of the ripening stages at harvest.

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