Quality of *Opuntia robusta* and its use in development of mayonnaise-like product

Aurea Bernardino-Nicanor ·
Emma Noemí Hinojosa-Hernández ·
José Mayolo Simitrio Juárez-Goiz ·
José Luis Montañez-Soto ·
María Eugenia Ramírez-Ortiz ·
Leopoldo González-Cruz

Revised: 10 February 2013 / Accepted: 28 March 2013 / Published online: 12 April 2013
© Association of Food Scientists & Technologists (India) 2013

Abstract The aim of this study was to characterize *Opuntia robusta* parenchyma and mucilage as foodstuffs. Solute absorption of *Opuntia robusta* parenchyma was studied, mucilage was used to develop a mayonnaise-like product as substitute emulsifier alternative to egg yolk and oil substitute. Shelf life of mayonnaise-like product was evaluated. Scanning electron microscopy demonstrated that oxalate calcium crystal were present in the *Opuntia robusta* parenchyma and mucilage with druses morphology; whereas that in the mayonnaise-like product were not observed calcium oxalate crystals, due probably to the product pH is acidic. The heat treatment of parenchyma at 50 °C, 65°Brix, had highest influence on the solute absorption (about 35 %). Results revealed that best mixture was the formulated with 26.79 % oil, 62.50 % mucilage and 10.71 % whey protein. Mucilage was the component showing the highest effect on all textural characteristics of mayonnaise-like product. The storage

temperature had highest effect on the textural characteristics of mayonnaise-like product than storage time. With the right combination of mucilage of *Opuntia*, oil and whey protein, it is possible to develop a low-fat mayonnaise with functional properties similar to those of commercial mayonnaise.

Keywords Mayonnaise-like · Mucilage · *Opuntia robusta* · Functional properties

Introduction

The *Opuntia* genus is composed of nearly 200 species world-wide (Chávez-Moreno et al. 2009), the plants of this genus are characterized by a high potential of biomass production (Pinos-Rodríguez et al. 2010) for this reason the pads of *Opuntia* are widely used for human consumption in semi-arid regions. The young tender pad or “nopalitos” are utilized as a fresh or cooked vegetable in a wide variety of dishes; plate cactus pad is filleted to make the culinary delight known as “nopal’s heart”. On the other hand the cladodes of *Opuntia* are used in folk medicine in the treatment of gastric mucosa diseases (Vigueras et al. 2001) and has been reported that probably, the mucilage of *Opuntia* is involved (Galati et al. 2001). However the plant of *Opuntia* genus also could be a good source of calcium in the common diet. Cladodes as well as other plant foods are rich in calcium, however the bioavailability of this element depend of sequestration level in the crystal form (McConn and Nakata 2004) for this reason only 16 and 9 % of total calcium is bioaccessible in *Opuntia*, on the other hand the cooking process did not affect significantly intestinal calcium bioaccessibility (Ramírez-Moreno et al.

A. Bernardino-Nicanor · E. N. Hinojosa-Hernández ·
J. M. S. Juárez-Goiz · L. González-Cruz (✉)
Departamento de Ingeniería Bioquímica, Instituto Tecnológico
de Celaya, Av. Tecnológico y A. García Cubas S/N. A.P. 57,
38010 Celaya, Guanajuato, Mexico
e-mail: lgonzalezcruz@yahoo.com

M. E. Ramírez-Ortiz
FES-Cuautitlan, Departamento de Ingeniería y Tecnología,
Universidad Nacional Autónoma de México, Av. 1° de Mayo
s/n, Col. Sta. María Las Torres, 05476 Cuautitlán Izcalli, Mexico

J. L. Montañez-Soto
Centro Interdisciplinario de Investigación para el Desarrollo
Integral Regional, Unidad Michoacán,
Instituto Politécnico Nacional,
Justo Sierra #28 Jiquilpan, Mich. C. P. 59510, México

2011) but the more mature nopal pads can be a natural source of calcium that might be included in human diets (Contreras-Padilla et al. 2011). Moreover, is important highlighted that the consumption of foodstuffs rich in oxalic acid can induced hyperoxaluria already in healthy individuals without disturbances in oxalate metabolism, for this reason the daily intake of oxalate should not exceed the 200 mg (Siener et al. 2006)

Recently, has been reported that nopal pads can be an important source for industrial production of hydrocolloids, because its mucilage has good emulsifying capability due to that reduce surface and interfacial tensions, stabilizes oil–water emulsions, formed small oil droplets, absorbed onto oil–water interfaces and the system did not flocculate (Sáenz et al. 2004).

Probably one of the oldest and most widely used dressings in the world today, is the mayonnaise which is an oil-in-water emulsion with high oil content 70–80 %. However, this is a disadvantage because high oil content principally cholesterol is linked with hypertension and obesity, for this reason actually low-fat-mayonnaises have been developed with yoghurt (Stern et al. 2008), xanthan gum, citrus fiber, guar gum (Hou-Pin et al. 2010), low methoxyl pectin and whey protein isolate (Liu et al. 2007), ingredients that confer desirable emulsifying properties and water retention, maintain the textural and sensory characteristics in low-fat-mayonnaise with only 25 % of oil (Stern et al. 2008), these properties have also been observed in the mucilage of nopal (*Opuntia sp.*). The objectives of this study, therefore, were to investigate the solute absorption capacity of *Opuntia robusta* parenchyma, characterize the calcium oxalate crystals presents in mucilage and mayonnaise-like product, to develop a mayonnaise-like product, partially replacing fat content with mucilage of *Opuntia* and study the storage life stability.

Materials and methods

Vegetative material

Young cladodes from *Opuntia robusta* Wendl var. *robusta* were obtained from Cuauhtépec, Hidalgo (Mexico). The cladodes were harvested manually at 12:00 p.m. and selected according to size: 32.3 ± 4.9 cm (large), 28.6 ± 0.5 cm (width) and 4.3 ± 0.2 cm (thickness), for a homogeneous state of maturity. The samples were stored at 4 °C in a refrigerator (LG, Model GR-452SH) for no longer than 24 h until used.

Obtention of mucilage and parenchyma

The epidermal tissue was removed from the cladodes using a knife and obtained the spongy parenchymatous tissue, which was subsequently cut into approximately 2 cm cubes, packed

in PVC-bags and stored in a freezer LG Model GR-452SH (LG electronics, México) until used.

Solute absorption capacity of the parenchyma

Solute absorption capacity was realized according to the method of Lira (1994) with some modifications. 600 g of cubes of parenchyma were dividing into three lots of 200 g each one. Each lot of cubes were heated in a stainless steel pan with 100 mL water at 50 °C (first lot), 70 °C (second lot) and 90 °C (third lot) for 30 min each one, then the cubes were separated using a cotton cloth. The cubes of each lot was divided into eight sub-lots, to each of which were added 50 mL of immersion solution (sucrose syrup 60°Brix to the first four and sucrose syrup 65°Brix to the second four). After adding the immersion solution all treatments were storage at 4 °C for 0 (control), 22, 44, 66 or 88 h. The solute absorption was determined by the variation in soluble solids content in the immersion solution and weight loss in the heat-treated parenchyma.

Mucilage preparation

The parenchyma cubes were placed in a stainless steel pan and heated at 90 °C by 30 min and then, the cubes were pressed and filtered to obtain the mucilaginous polysaccharides. The mucilage obtained was concentrate to 10 % of soluble solids on a water bath.

Identification of calcium oxalate crystals for Scanning Electron Microscopy (SEM)

In order to visualized the calcium oxalate crystals in the mucilage heated at 90 °C, 30 min, SEM was carried out with a JEOL scanning electron microscope (JEOL, type EX-1200, Japan) operated at 15 kV. The samples were mounted in a double-sided carbon tape and covered with roughly 10 nm of gold in a Denton sputter coater.

Light microscopy

The glass microscope slide was coated with a mayonnaise sample and placed on the stage of a light microscope Leica DM2500 M (Leica Microsystems, Wetzlar, Germany) to obtain photomicrographs using 100x dry objectives. Photographs were taken using a Leica camera DFC450.

Preparation of mayonnaise-like product

The water phase was first prepared by mixing all ingredients (Table 1) in a 1 L plastic beaker, except the corn starch and sunflower oil. Then the oil was carefully mixed with the water phase. In this study, for the elaboration of low-fat

Table 1 Ingredients (%) formulation of the mayonnaise

Ingredient	F1	F2	F3	F4	F5	F6	F7	F8	F9
Sunflower oil	20.00	17.86	16.13	30.00	26.79	24.19	40.00	35.71	32.26
Mucilage	80.00	71.43	64.52	70.00	62.50	56.45	60.00	53.57	48.39
Whey protein	0.00	10.71	19.35	0.00	10.71	19.35	0.00	10.71	19.35

In addition, to each formulation was added sugar 21 %; spices 20 %, corn starch 15.7 %, mustard 8.5 % and salt 4.3 %

mayonnaises, the sunflower oil was replaced by *Opuntia* mucilage and whey proteins at different levels (Table 1). Mayonnaises were aseptically transferred to sterile 25 g glass jars and storage at 25 °C until testing.

Texture analysis of mayonnaise-like product

In order to determine the texture attributes of mayonnaise-like product, texture measurements were carried out with the TA 500 Texture Analyser (Lloyd Instruments Ltd., UK) with a 1 kg load cell. The surfaces of the samples were carefully smoothed with a spatula to produce smooth surfaces perpendicular to the cylinder axis (acrylic cylinder with 1-inch diameter). Two cycles were applied at a constant cross-head velocity of $1 \text{ mm} \cdot \text{s}^{-1}$ to a sample depth of 3 mm. From the resulting force-time curve were obtained only the texture attributes firmness, adhesive force and adhesiveness.

Characterization of mayonnaise-like product by SEM and light microscopy

In order to visualize the changes in the calcium oxalate crystals in the mayonnaise-like product, a similar methodology used in the characterization of calcium oxalate crystal in the mucilage was carried out.

Mayonnaise shelf life

The sample with best texture profile was stored in temperature controlled incubators set at 25 ± 2 °C, 35 ± 2 °C and 45 ± 2 °C for 8 weeks. Texture profile analysis was carried out at 4 weeks intervals starting from the day of manufacture (0 day of storage); 4 weeks (30 days of storage) and 8 weeks (60 days of storage).

A total of 21 glass jars of 25 g were elaborated and were divided in seven different treatments with three glass jars each: The 1st treatment was the initial sample (control), 2nd, 3rd and 4th treatments were stored at 25, 35 and 45 °C respectively for up to 30 d. 5th, 6th and 7th series were stored at 25, 35 and 45 °C respectively for up to 60 d.

Statistical analysis

The quantitative data were expressed as the mean $\pm$ standard deviation, and the analysis of variance (ANOVA) was carried out followed by a Tukey's test. SAS software was used for the data analysis, and all experimental determinations were assayed in triplicate.

Results and discussion

Calcium oxalate crystals morphology

The calcium oxalate crystals present in heat-treated mucilage obtained from *Opuntia robusta* were identified as druses, in general these druses are aggregates of hundreds of small crystals with the same general appearance, however in *Opuntia* the crystallites have acute points and all of them appear to grow out from the center of the druse (Fig. 1a), these characteristics indicate that the principal function of oxalate calcium crystals in *Opuntia* is protection, as well as raphides have acute points, this characteristic is predominant in the *Opuntia* genus feature that distinguishes them from other cacti (Monje and Baran 2002). In others *Opuntia* species are have found crystals with the same morphological aspect (starlike druses) which are almost ubiquitous in *Opuntia* species (Malainine et al. 2003).

Fig. 1 Calcium oxalate crystal in *Opuntia robusta* Wendl. **a** Isolate druse **b** Crystal sand surrounding druse

Fig. 2 Calcium oxalate crystals in *Opuntia robusta* mucilage
a Early druse formation b druse

In parenchymal tissue of *Opuntia robusta* the presence of crystal sand were observed in addition to druses both along the parenchyma; however in most cases structures of crystal sand were surrounding the druse crystal (Fig. 1b).

The druses with a size of about 100 to 400 µm are scattered more or less throughout the mucilaginous crude polysaccharides, generating irregularities and modifying the surface. The cavities formed in the mucilaginous crude polysaccharides are heterogeneous in their architecture and can surround all or partially the druse (Fig. 2). The predominant presence of calcium oxalate crystals apparently is due to the advantage that the druses are water insoluble (Monje and Baran 2002) and can act as reserve source of calcium. Diverse studies indicate that the formation of calcium oxalate crystals is in response to high levels of free calcium (Keates et al. 2000; Kostman et al. 2001).

On the other hand the sand crystals that surrounded the druses apparently are calcium oxalate dehydrate crystals (weddellite) which has been observed in others *Opuntia* species where the weddellite could be either a pre-storage or a post-storage and premobilization form which can be readily dissolved and directed to its use area (Malainine et al. 2003).

The heat treatment had a reducing effect on calcium oxalate crystals since these no were observed in the mucilage concentrated at 10 °Brix (Fig. 3a) neither in mayonnaise elaborated with this mucilage (Fig. 3b). It appears that the heat treatment increased the rate of reduction of calcium oxalate crystals, through different possible mechanisms like solubilization, leaching, cell collapse and complexing. These results are important for the development of a new foods based on *Opuntia robusta* mucilage since the heat treatment at higher temperatures reduce the concentration

of calcium oxalate crystals, avoiding adverse effects that are often associated with consumption of foods with high levels of calcium oxalate (Haughes and Norman 1992).

Solute absorption in parenchyma

The heat treatment influenced on the solute absorption capacity by the parenchyma of *Opuntia robusta* (Fig. 4a). The greater absorption of solutes was obtained when the parenchyma of *Opuntia robusta* was heated to 50 or 70 °C, because that solutes absorption of the parenchyma heated to 90 °C was similar than the control. It was observed too that the temperature of the thermal treatment has a considerable influence on the weight loss of the parenchyma (Fig. 4b). The parenchyma without thermal treatment (control) had higher weight loss (about 70 %) than the thermally treated samples. The lower weight loss (about 10 %) was obtained when the parenchyma was heated at 90 °C. These results are probably attributed to that by the Ca^{2+} -mediated dimeric association of pectin gels in *Opuntia* which is favorable to formation of a gel network even at 85 °C (Cárdenas et al. 2008) that stabilize the polysaccharides gel structure avoiding the liberation free compounds of the parenchyma.

Diverse research about *Opuntia* mucilage indicate that this compound is stable even at temperatures above 70 °C (Lee et al. 1998), for his high pectin concentration can have diverse inter- and intramolecular interactions (Majdoub et al. 2001) that permit the formation of a superficial layer that may protect the parenchyma of later dehydration in sugar syrup. In addition has been observed that the *Opuntia* pectins are low methoxyl that led to the formation of elastics

Fig. 3 Mucilage and mayonnaise-like product micrograph a Mucilage concentrate at 10 % soluble solids b Mayonnaise-like product

Fig. 4 Influence heat treatment and storage period on the *Opuntia robusta* parenchyma solute absorption capacity. The values are means $\pm$ SD of triplicate measurements. Values with different letters are significantly different ($P \leq 0.05$) **a** Soluble Solid loss in immersion

solution, by heat treatment, **b** Weight loss in parenchyma, by heat treatment, **c** Soluble Solid loss in immersion solution, by storage period, **d** Weight loss in parenchyma, by storage period

gels and the gelling process is thermoreversible (Goycoolea and Cárdenas 2003).

However at lower temperature (50 and 70 °C) only a highly cooperative 2 helix junctions formed associated with a conformational transition driven by temperature, charge neutralization, lower coil mobility and followed by helix aggregation (Cárdenas et al. 2008) this lead to reduced the stability of gel network which can result in its collapse during immersion of parenchyma which would cause dehydration of the parenchyma during the immersion process.

The storage life of parenchyma of *Opuntia robusta* not influenced on its absorption capacity since the amount of solutes absorbed after 88 h (Fig. 4c). However, apparently as a result of the differential density condition in the parenchyma, the exchange effects is reflected on the parenchyma weight (Fig. 4d) which is lower than in the parenchyma with heat treatment, this may be attributable to that in *Opuntia* genus, the water-soluble carbohydrate content decreases by hydric stress effect (Nerd and Nobel 1991) for this reason the weight loss values for stored parenchyma is lower (10 %) than parenchyma with heat treatment. Specifically, in a system where two compounds with different concentration are in

contact, exchange of soluble-compounds reaches a point where the concentration ratios in the two compounds reach

Table 2 Instrumental texture characteristics of Mayonnaise-like product

Formulation	Firmness (N)	Adhesiveness (N)	Adhesive force (N*s)
F1	0.123 $\pm$ 0.009 ^d	0.710 $\pm$ 0.056 ^a	0.2610 $\pm$ 0.020 ^{d,e}
F2	0.153 $\pm$ 0.009 ^d	0.081 $\pm$ 0.004 ^f	0.3548 $\pm$ 0.028 ^d
F3	0.166 $\pm$ 0.008 ^d	0.089 $\pm$ 0.005 ^{e,f}	0.3811 $\pm$ 0.019 ^d
F4	0.496 $\pm$ 0.029 ^c	0.158 $\pm$ 0.006 ^c	0.1502 $\pm$ 0.007 ^c
F5	0.738$\pm$0.051^b	0.338$\pm$0.020^d	0.8208$\pm$0.057^c
F6	1.059 $\pm$ 0.084 ^a	0.556 $\pm$ 0.022 ^c	1.4390 $\pm$ 0.071 ^a
F7	0.150 $\pm$ 0.004 ^d	0.077 $\pm$ 0.003 ^f	0.1803 $\pm$ 0.007 ^c
F8	1.144 $\pm$ 0.068 ^a	0.663 $\pm$ 0.039 ^{a,b}	1.4320 $\pm$ 0.071 ^a
F9	1.108 $\pm$ 0.044 ^a	0.594 $\pm$ 0.023 ^{b,c}	1.4500 $\pm$ 0.087 ^a
Comercial	0.715 $\pm$ 0.028 ^b	0.388 $\pm$ 0.015 ^d	0.9974 $\pm$ 0.059 ^b

Refer to Table 1 for F1-F9. Different letters in each column indicate significant statistical differences ($P \leq 0.05$). The values are means $\pm$ SD of triplicate measurements. Data of adhesiveness and adhesive force are absolute values

Fig. 5 Micrographs of mayonnaise-like product made with **a** High oil content **b** Low oil content (Formulation 5)

their equilibrium values, for this reason the loss-weight in parenchyma stored by 21 days is highest that at 7 and 14 days.

Textural characteristics of the mayonnaise-like product

All the texture parameters determined are shown in Table 2. The results indicate that the ratio of mucilage:oil influencing the textural properties, a low mucilage percentage resulted in a harder structure (F9), whereas lower firmness value was obtained with a high mucilage percentage (F1). The highest values of adhesive force were presents in samples with high content of whey proteins (19.35 g) and then, in samples containing 10.71 and 0 g of whey proteins. The three-component interaction (mucilage-oil-whey protein) had a more notable influence on adhesive force because the adhesive force was significantly higher for samples containing the three components and lower in those with only mucilage and oil. Increased whey protein concentration also increased sample adhesive force. It has been observed that the addition of proteins generates a yields stress for the emulsion higher than samples without protein added, inhibiting the creaming profile (Sun et al. 2007).

The addition of a concentration of 26.79 g oil was the optimal to obtain a mayonnaise-like product with textural characteristics similar to commercial mayonnaise (F5). The mucilage addition increases the elasticity of the emulsion by itself as result of the formation of a strong gel-like structure in the continuous phase owing to its high pectin content (Goycoolea and Cárdenas 2003) imparting a more firm and adhesive structure and also yielding smaller droplet diameters because of a reduced coalescence process during emulsification (Nikzade et al. 2012).

The use of *Opuntia robusta* mucilage as a single emulsifier can yield an undesired emulsion, because of its high-water content, for this reason the addition of whey protein is beneficial because acts as synergist agent allowing to obtain mayonnaise-like product with adequate textural properties and decreasing the oil concentration at a much lower concentration (F5) than reported earlier for low fat mayonnaise-like (Hou-Pin et al. 2010; Liu et al. 2007). In low-fat-oil-in-water emulsions it has been observed that firmness and adhesiveness increased with the concentration of protein, xanthan gum and oil (Raymundo et al. 2002) or to achieve a complete emulsion

it was necessary add at least two gum (Hou-Pin et al. 2010) or protein. On the other hand the oil content too has an important role in the low-fat-mayonnaise elaboration but manufacturers usually try reduce the oil content of mayonnaise as much as possible, however, in this research, the results showed that in mayonnaise-like product with an oil content lower or greater than 15 %, their textural characteristics are significantly modified, similar results were obtained for yoghurt-modified mayonnaise (Stern et al. 2008). This result corroborates the potential of *Opuntia robusta* mucilage as emulsifier and oil-substitute in the food manufacturing (Goycoolea and Cárdenas 2003).

Microscopic examination

The particle mean diameter of some mayonnaise samples (F7, F8, F9 and F4) was above 37 µm and apparently larger than the control (Fig. 5). High oil concentration in solution change the oil droplet size and dispersion in addition weak-gel additives poorly disperse in solution induce the formation of large particle size (Hou-Pin et al. 2010). However, in the formulation 5, the oil droplets were in a size similar to control (21 to 25 µm), probably similar conditions in the dispersal situation of mayonnaise-like product was due to the formation of three-dimensional networks between mucilage and whey protein.

Table 3 Influence storage time and temperature on instrumental texture characteristics of mayonnaise-like product (Formulation 5)

Storage conditions		Firmness (N)	Adhesiveness (N)	Adhesive force (N*s)
Time (days)	Temperature (°C)			
Initial		0.7780±0.015 ^a	0.4440±0.019 ^a	1.4403±0.009 ^a
30	25	0.7380±0.042 ^a	0.3380±0.008 ^b	0.9972±0.082 ^b
	35	0.7145±0.052 ^a	0.3270±0.008 ^b	0.8208±0.013 ^c
	45	0.5483±0.019 ^b	0.2600±0.020 ^c	0.4790±0.043 ^d
60	25	0.5285±0.004 ^b	0.2500±0.009 ^c	0.9689±0.029 ^b
	35	0.2646±0.004 ^c	0.1066±0.004 ^d	0.4783±0.043 ^d
	45	0.1280±0.016 ^d	0.0926±0.003 ^d	0.4461±0.042 ^d

Refer to Table 1 for F5; Different letters in each column indicate significant statistical differences ($P \leq 0.05$). The values are means $\pm$ SD of triplicate measurements. Data of adhesiveness and adhesive force are absolute values

On the other hand the mayonnaise-like product with lower oil content (F1, F2 and F3) exhibited relatively larger spaces surrounded by looser aggregated droplets.

The droplets of different size (polydisperse) in which the small droplets were trapped between the large ones occurred in the formulations 4, 6, 7, 8 and 9. Diverse authors have been observed that the viscosity of polydisperse emulsions was significantly lower than that observed in monodisperse emulsions (Worrasinchai et al. 2006) however in this study a complete different behavior was observed. On the other hand, reduction of the oil content also dramatically decreased viscosity in the formulations 1, 2 and 3 which showed relatively open and loose structures, with a network of aggregated droplets containing a large number of interspaced voids of varying dimensions.

Shelf life stability

The textural characteristics of the mayonnaise-like product expressed in terms of firmness, adhesiveness and adhesive force were measured at 25, 35 and 45 °C for 60 days (Table 3). The adhesiveness and adhesive force of mayonnaise-like product storage at 45 °C decreased dramatically with a steady decline. The mayonnaise-like product showed high stability during storage at 25 and 35 °C, 30 days. The textural characteristics of mayonnaise-like product decreased significantly for samples stored at higher temperatures. The instability of texture characteristics could be due to the very rapid flocculation and/or coalescence of small droplets occurred with increasing storage temperature (Asano and Sotoyama 1999). Apparently the mayonnaise-like product may possess good whey protein-*Opuntia robusta* mucilage interaction that retains their stability and textural characteristics by forming protective steric barrier around the oil droplet (Ghoush et al. 2008).

Conclusions

The heat treatment on *Opuntia* parenchyma and mucilage caused the elimination of calcium oxalate crystals which is beneficial since it allows its use as new foodstuffs. It was evidenced that a heat treatment over 70 °C on *Opuntia* parenchyma stabilizes the matrix and decrease the dehydration activity. A mayonnaise-like product with similar characteristics to commercial mayonnaise prepared with egg yolk was formulated using 26.79 % oil, 62.50 % mucilage and 10.71 % whey protein. A mayonnaise-like product with shelf life stable at 25 °C can be formulated with a mucilage-protein as egg substitute, however, significant changes in the texture were observed as a result of increasing storage temperature (35 or 45 °C).

References

- Asano Y, Sotoyama K (1999) Viscosity change in oil/water food emulsions prepared using a membrane emulsification system. *Food Chem* 66:327–331
- Cárdenas A, Goycoolea FM, Rinaudo M (2008) On the gelling behaviour of “nopal” (*Opuntia ficus-indica*) low methoxyl pectin. *Carbohydr Polym* 73:212–222
- Chávez-Moreno CK, Tecante A, Casas A (2009) The *Opuntia* (Cactaceae) and *Dactylopius* (Hemiptera: Dactylopiidae) in Mexico: a historical perspective of use, interaction and distribution. *Biodivers Conserv* 18(13):337–3355
- Contreras-Padilla M, Pérez-Torero E, Hernández-Urbiola MI, Hernández-Quevedo G, Del Real A, Rivera-Muñoz EM, Rodríguez-García ME (2011) Evaluation of oxalates and calcium in nopal pads (*Opuntia ficus-indica* var. *redonda*) at different maturity stages. *J Food Compos Anal* 24:38–43
- Galati EM, Monforte MT, Tripodo MM, d’Aquino A, Mondello MR (2001) Antiulcer activity of *Opuntia ficus indica* (L.) Mill. (Cactaceae): ultrastructural study. *J Ethnopharmacol* 76:1–9
- Ghoush MA, Samhouri M, Al-Holy M, Herald T (2008) Formulation and fuzzy modeling of emulsion stability and viscosity of a gum-protein emulsifier in a model mayonnaise system. *J Food Eng* 84:348–357
- Goycoolea F, Cárdenas A (2003) Pectins from *Opuntia spp*: a short review. *JPACD* 5:17–28
- Haughes J, Norman RW (1992) Diet and calcium stones. *Can Med Assoc J* 146:137–143
- Hou-Pin S, Chuang-Ping L, Tan-Ang L, Ruo-Syuan H (2010) Development of low-fat mayonnaise containing polysaccharide gums as functional ingredients. *J Sci Food Agric* 90:806–812
- Keates SE, Tarlyn NM, Loewus FA, Franceschi VR (2000) L-Ascorbic acid and L-galactose are sources for oxalic acid and calcium oxalate in *Pistia stratiotes*. *Phytochemistry* 53:433–440
- Kostman TA, Tarlyn NM, Loewus FA, Franceschi VR (2001) Biosynthesis of L-Ascorbic acid and conversion of carbons 1 and 2 of L-Ascorbic acid to oxalic acid occurs within individual calcium oxalate crystal idioblasts. *Plant Physiol* 125:634–640
- Lee SP, Wang K, Ha YD (1998) Functional properties of mucilage and pigment extracted from *Opuntia ficus-indica*. *J Korean Soc Food Sci Nutr* 27:821–826
- Lira SRH (1994) Fisiología vegetal. Trillas (ed). Universidad Autónoma Agraria. pag. 55–58, 173–174.
- Liu H, Xu XM, Guo SD (2007) Rheological, texture and sensory properties of low-fat mayonnaise with different fat mimetics. *LWT-Food Sci Tech* 40(6):946–954
- Majdoub H, Roudesli S, Deratani A (2001) Polysaccharides from prickly pear peel and nopals of *Opuntia ficus-indica* extraction, characterization and polyelectrolyte behavior. *Polym Int* 50:552–560
- Malainine ME, Dufresne A, Dupeyre D, Vignon MR, Mahrouz M (2003) First evidence for the presence of weddellite crystallites in *Opuntia ficus indica* parenchyma. *Z Naturforsch C* 58:812–816
- McConn MM, Nakata PA (2004) Oxalate reduces calcium availability in the pads of the prickly pear cactus through formation of calcium oxalate crystals. *J Agr Food Chem* 52:1371–1374
- Monje PV, Baran EJ (2002) Characterization of calcium oxalates generated as biominerals in cacti. *Plant Physiol* 128(2):707–713
- Nerd A, Nobel PS (1991) Effects of drought on water relations and nonstructural carbohydrates in cladodes of *Opuntia ficus-indica*. *Physiol Plant* 81:495–500
- Nikzade V, Mazaheri TM, Saadatmand-Tarzan M (2012) Optimization of low-cholesterol-low-fat mayonnaise formulation: efectct of using soy milk and some stabilizer by a mixture design approach. *Food Hydrocoll* 28:344–352
- Pinos-Rodríguez JM, Velázquez JC, González SS, Aguirre JR, García JC, Álvarez G, Jasso Y (2010) Effects of cladode age on biomass

- yield and nutritional value of intensively produced spineless cactus for ruminants. *S Afri J Anim Sci* 40(3):245–250
- Ramírez-Moreno E, Díez-Marqués C, Sánchez-Mata MC, Goñi I (2011) In vitro calcium bioaccessibility in raw and cooked cladodes of prickly pear (*Opuntia ficus-indica* L. Miller). *LWT-Food Sci Tech* 44:1611–1615
- Raymundo A, Franco JM, Empis J, Sousa I (2002) Optimization of the composition of cow-fat oil-in-water emulsions stabilized by white lupin protein. *J AOCS* 79(8):783–790
- Sáenz C, Sepúlveda E, Matsuihiro B (2004) *Opuntia spp* mucilage's: a functional component with industrial perspectives. *J Arid Environ* 57:275–290
- Siener R, Hönow R, Voss S, Seidler A, Hesse A (2006) Oxalate content of cereals and cereal products. *J Agr Food Chem* 54(8):3008–3011
- Stern P, Pokorny J, Šediva A, Panovska Z (2008) Rheological and sensory characteristics of yoghurt-modified mayonnaise. *CJFS* 26(3):190–198
- Sun C, Gunasekaran S, Richards MP (2007) Effect of xanthan gum on physicochemical properties of whey protein isolate stabilized oil-in-water emulsions. *Food Hydrocoll* 21(4):555–564
- Vigueras G, Portillo AL, Portillo L (2001) Uses of *Opuntia* species and the potential impact of *Cactoblastis cactorum* (Lepidoptera: Pyralidae) in Mexico. *Fla Entomol* 84(4):493–498
- Worrasinchai S, Supphantharika S, Pinjai S, Jamnong P (2006) β -Glucan prepared from spent brewer's yeast as a fat replacer in mayonnaise. *Food Hydrocoll* 20:68–78