academicJournals

Vol. 10(15), pp. 1810-1816, 9 April, 2015
DOI: 10.5897/AJAR2015.9484
Article Number: ED335F552473
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Minimally processed prickly pear stored under different temperatures and packaging

Kelly M. Marques[1], Ana Carolina A. Miguel[2], Vanessa C. Galati[1], Cristiane M. A. Morgado[1], Claudia F. M. Mattiuz[2] and B. Mattiuz[1]*

[1]Faculdade de Ciências Agrárias e Veterinárias, UNESP - Univ Estadual Paulista, Campus de Jaboticabal, São Paulo, Brazil.
[2]Escola Superior de Agricultura 'Luiz de Queiroz', Universidade de São Paulo, Piracicaba, São Paulo, Brazil.

Received 6 Janaury, 2015; Accepted 7 April, 2015

The desirability of minimally processed products makes the prickly pear (*Opuntia ficus indica* (L.) Mill) an option for this market. The aim of this work was to verify the effects of storage temperatures and packaging on the conservation of minimally processed prickly pear. Ripe fruits with greenish exterior were used, and after peeling and sanitization were placed into one of the following storage methods: (1) Transparent polyethylene terephthalate (PET) packaging with lid; (2) Plastic coating PD 900®; (3) Polyvinyl chloride layer coating layer coating of 11 µm, or (4) 14 µm thickness. The units were stored for 12 days in refrigerated chambers at 3±1°C and 80±2.5% RH, or at 6±1°C and 70±2.5% RH. Analysis of fresh mass loss, CO_2 rate, luminosity, chromaticity, soluble solid content, titratable acidity, carotenoids, and sensory analysis for appearance and color were performed every three days. The PET packaging with lid, associated with storage at 3ºC, promoted the best results for quality maintenance of minimally processed prickly pears for up to twelve days.

Key words: Carotenoids, minimal processing, *Opuntia ficus indica* (L.) Mill, postharvest, quality.

INTRODUCTION

The Indian fig, or also called prickly pear (*Opuntia fícus indica* (L.) Mill.), is a Mexican species that belongs to the Cactaceae family (Grangeiro et al., 2007). The fruit has high nutritional value, containing fiber, soluble carbohydrates, calcium, magnesium, and vitamins (El-Kossori et al., 1998). The presence of woody sharp spines, which can puncture human skin causing an irritation are a great disadvantage of this fruit, and restrict its intake. Therefore, minimal processing, by removing its peel and spines, would particularly contribute to enhancing its *in natura* consumption (Piga et al., 2000; Sáenz et al., 2001).

Minimally processed fruits and vegetables are fresh products submitted to cleaning, washing and selection processes, followed by physical changes, such as peeling, slicing and cutting, making them ready for consumption or another preparation (Pereira et al., 2003; Moretti, 2007). Despite the practicality and convenience, vegetable processing promotes an increase in metabolism accompanied by biochemical alteration and degradation that may affect both sensory and nutritional quality of minimally processed products (Allende et al., 2006; Corrales-García et al., 2006). Furthermore, the high sugar content (12 ºBrix) and low acidity (0.95 µg

*Corresponding author. E-mail: benhur@fcav.unesp.br. Tel: (+55) 16-3209-2675. Fax: (+55) 16-3209-7408

Table 1. Characteristics of the layer coatings used in packaging.

Plastic layers	Characteristics	Permeability rate (ml STP m^{-2} day^{-1})	
		O_2	CO_2
PD 900	Thermoretractable plastic material	3.147	19.334
PVC 11 µm	Stretchable plastic film	13.464	89.604
PVC 14 µm	Stretchable plastic film	11.373	85.136
PET	Polyethylene rigid packaging	12.081	-

Data obtained according to the methodology described by Sarantópoulos et al. (2002) and Arruda et al. (2003).

citric acid g^{-1}) in prickly pears (Marques et al., 2011) are characteristics that may limit fresh fruit storage time due to high susceptibility to microbiology deterioration (Corbo et al., 2005). The processing wounds also lead to physiological changes that may result in appearance damage, and are considered one of the major problems of minimal processing. Furthermore, senescence may be stimulated, and unpleasant odors released, through the increased respiration process and ethylene production in the wound areas (Mattiuz et al., 2003). Hence, it is essential for the conservation of minimally processed fruits, that proper packaging and refrigeration systems are used throughout processing and distribution, to prolong the shelf life of the fruit and to reduce the growth of the microbial population (Corbo et al., 2004; Corrales-García, 2009; Del Nobile et al., 2009).

The aim of the present work was to verify the effect of storage temperatures and packaging on the conservation of minimally processed prickly pear.

MATERIALS AND METHODS

Plant material and experiment implementation

Ripe prickly pears, with a greenish yellow exterior and an orange pulp, were harvested from an orchard located in Valinhos County, São Paulo State, Brazil (22º 58' S and 46° 59' W). The fruits were then selected according to size and taken to the Technology Laboratory of Agricultural Products at FCAV/UNESP, Jaboticabal County, São Paulo State. Upon arrival to the laboratory, the fruits were put through a new selection process, washed with water and detergent, rinsed, and sanitazed in 0.66% dichlorine s. dihydrate sodium triazinatrione (Sumaveg®) (200 mg $L^{-1}$of free chlorine) for 5 min for superficial disinfection. The fruits were left to dry at 20ºC on a previously sanitized surface covered with paper. When dry, the fruits were taken into the cold room, previously sanitized and regulated at 12±2°C, where they were left to cool for 12 h before processing.

The processing stage started with peeling and end removal using a sharp knife. The fruits were then rinsed in 0.033% dichlorine s. dihydrate sodium triazinatrione (Sumaveg®) (10 mg $L^{-1}$of free chlorine) for 30 s and left for drainage of excess water for 4 min. Subsequently, the fruits were packaged in 1,000 ml transparent polyethylene terephthalate (PET) containers (Neoform® brand, N-94), which were closed with four different materials (treatments): (1) With its own lid (PET); (2) Plastic coating PD 900®; (3) 11 µm, or (4) 14 µm polyvinyl chloride layer coating (PVC). The units were stored in refrigerated chambers for 12 days at 3±1°C and 80±2.5% RH, or at 6±1°C and 70±2.5% RH.

The experimental design was entirely randomized and the treatments were arranged in a 4x2 factorial scheme: Four types of packaging and two refrigeration temperatures. There were four replicates per treatment, each with four fruits representing approximately 240 g of product.

The characterization of the layer coating, according to the permeability rate to oxygen and carbon dioxide, is shown in Table 1.

Evaluations

Evaluations of the following parameters were performed every three days: fresh mass, using a digital scale with a 2,000 g capacity and 0.1 g precision; CO_2 percentage inside the packaging using a Check Mate model PBI-DANSENSOR; crushed pulp coloration measured by a MINOLTA CR 400 colorimeter (KONICA MINOLTA), which was expressed by Luminosity values (L) (100=white; 0=black) and chromaticity (Minolta Corp., 1994); titratable acidity content (µg citric acid g^{-1}) and soluble solids (ºBrix) as indicated by AOAC (1997); carotenoid contents (µg carotenoid g^{-1} of pulp), being the supernatant absorbance measured by spectrophotometer at λ = 663 nm for chlorophyll a and λ = 646 nm for chlorophyll b; λ = 470 nm for carotenoids, and the calculations of levels were obtained according to Lichtenthaler (1987) equations; sensory analysis, carried out by 20 untrained tasters, using a hedonic scale of 5 points for appearance and color, varying from 5 (excellent), 4 (good), 3 (regular), 2 (poor) and 1 (bad), adapted from Peryam and Girardot (1952). Microbiological analyses were conducted to monitor the fruits for the presence of microorganisms, measuring the average number (UFC/g) of fecal and total coliforms (nº/g) , and mesophilic microorganisms in the fruits. Samples were taken at the beginning (0 day), middle (6^{th} day) and final (12th day) of the experiment. Microorganism numbers were determined by the innoculation of vegetable homogenates, and their dilutions in Butterfield buffer, on Agar, under aerobic conditions at 45ºC (ICMSF, 1978; APHA, 1992).

Data analysis

To analyze the variance (ANOVA) of the data, an F test was conducted using software SAS (SAS Institute Inc.), and when it was significant, the average values of each variable were compared with the Tukey test with 95% confidence intervals (P≤0.05).

RESULTS AND DISCUSSION

The PD 900 and PET packaging were the most efficient in keeping fresh mass, presenting lower losses when compared with the fruits from the PVC packaging either at 3 or 6°C (Table 2).

Table 2. Fresh mass loss, CO_2 content, luminosity, and chromaticity of minimally processed prickly pears stored under different temperatures and packaging for 12 days.

Packaging	Fresh mass loss (%)		CO_2 content (%)		Luminosity		Chromaticity	
	6ºC	3ºC	6ºC	3ºC	6ºC	3ºC	6ºC	3ºC
PD 900	0.165^{aC}	0.074^{bC}	1.73^{aA}	0.83^{bA}	31.33^{aA}	31.20^{aB}	16.84^{aB}	15.76^{bD}
PVC 11 µm	0.854^{aA}	0.426^{bA}	0.94^{aC}	0.60^{bB}	31.07^{aA}	31.33^{aB}	17.81^{aA}	16.70^{bC}
PVC 14 µm	0.731^{aB}	0.276^{bB}	1.19^{aB}	0.62^{bB}	31.40^{bA}	33.27^{aA}	16.65^{bB}	18.08^{aB}
PET	0.120^{aC}	0.071^{aC}	0.86^{aC}	0.33^{bC}	30.93^{bA}	33.33^{aA}	16.24^{bB}	19.50^{aA}

Means followed by, at least,one same letter, lowercase in the line and upper case in the column, for each variable, do not differ from each other by the Tukey test ($P<0.05$).

These results can be associated with the permeability difference among the tested packaging materials (Table 1). PVC was more permeable to water vapor than polyethylene, which in turn, is more permeable than polyolefin (Sarantópoulos et al., 2002). More significantly, the major fresh mass loss (average 0.9%) on 11 µm PVC coated products was considered minor (Table 2), when compared with what was indicated by Chitarra and Chitarra (2005), who mentioned that 3 to 6% of fresh mass loss is enough to degenerate fruit quality, inducing withering. According to Piga et al. (2003), plastic layers help to maintain a high humidity inside the packaging, reducing fresh mass loss by the minimally processed prickly pears stored in plastic packaging coated with a highly gas permeabilitypolyolefin plastic layer. The samples presented a maximum loss of 0.15 g/100 g after nine days under 4ºC.

When we compared storage temperatures, fruits kept at 3ºC presented lower fresh mass losses than those stored at 6ºC (Table 2). Products stored at 6ºC presented an average of 45% more fresh mass loss over those kept at 3ºC. This is the result of the lower vapor pressure difference (VPD) between the product and the vapor pressure in the packaging internal environment. The packaging environment is directly influenced by the relative humidity and the difference in temperature between the product and the storage environment. The smaller the difference, as shown with the lower storage temperature, the less water lost by the product (Chitarra and Chitarra, 2005). Product respiration and transpiration are restricted under low temperatures, reducing the water content in plant tissues (Chitarra and Chitarra, 2005). Minimally processed prickly pears packaged in polystyrene, coated with a polyolefin layer and stored under 4°C, showed a reduction in the respiration rate and minor fresh mass loss when compared with those stored under higher temperatures, such as 15°C (Piga et al., 2000).

The highest CO_2 concentrations inside the packaging, regardless the storage temperature, were observed in the PD 900 packaging. The ones with PET lid showed a lower concentration of the gas, evidencing that this coating is the most permeable to CO_2 (Table 2). Despite the lower concentration of CO_2 inside the packaging, the alteration in the gaseous composition was minor, which led to the conclusion that the tested packaging did not promote a significant alteration in the gaseous composition inside the package (Table 2). Cantwell (1992) recognized that the utilization of climates with 2-8% of O_2 and 5-15% of CO_2 extend shelf life and enable the commercialization of minimally processed fruits and vegetables; however, there is a specific climate indicated for each agricultural product.

When the effect of the refrigeration temperature was analyzed, a higher accumulation of CO_2 was found inside the packaging stored at 6ºC,when compared with the ones at 3ºC (Table 2). Higher temperatures increase the fruit respiration rate, as well as gas permeability of the packaging layers (Sarantópoulos et al., 2003). Minimally processed prickly pears stored at 10ºC, after 8 days, presented respiration rates higher than the treatments at 6 and 2ºC (Añorve Morga et al., 2006). The atmospheric composition of the storage environment also depends on the layer permeability, speed of O_2 consumption, and CO_2 release from the packaged product (Chitarra and Chitarra, 2005).

A study on minimally processed prickly pears stored at 4ºC, testing three types of plastic layers with different densities, resulted in a significant difference in luminosity of the fruit stored under the analyzed plastic layers, with 25 µm polypropylene film providing higher luminosity values for fruit pulp (Corrales-García et al., 2006). In this current study, products stored at 3ºC presented the highest luminosity values, implying that the fruit pulps became less dark than the ones stored at 6ºC (Table 2). At 3ºC, the PET packaging contrasted from the others by presenting fruits with the highest luminosity values, although it did not significantly differ from the 14 µm PVC packaging. The minor darkening pattern in PET packaging products might be due to the lower fresh mass loss, resulting in higher cellular hydration, making the cells less prone to oxidation. It is also possible that the lower temperature resulted in a reduction in activity of the enzymes responsible for enzymatic browning (Darezzo, 2000). The storage temperature is the most important environmental factor, both for commercial interest and controlling senescence, since storage under lower

Table 3. Soluble solid contents (SS), titratable acidity (TA), and SS/TA ratio of minimally processed prickly pears stored under different temperatures and packaging for 12 days.

Packaging	SS (°Brix)		TA (µg Ac. citric acid g^{-1})		SS/TA	
	6ºC	3ºC	6ºC	3ºC	6ºC	3ºC
PD 900	12.09^{aA}	12.35^{aAB}	0.653^{bAB}	0.685^{aB}	18.46^{aC}	18.27^{aB}
PVC 11 µm	12.00^{aA}	12.22^{aAB}	0.667^{aA}	0.657^{aC}	18.30^{bC}	18.76^{aA}
PVC 14 µm	12.16^{aA}	12.17^{aB}	0.653^{bAB}	0.726^{aA}	18.88^{aB}	17.10^{bC}
PET	12.18^{bA}	12.57^{aA}	0.635^{bB}	0.717^{aA}	19.39^{aA}	17.29^{bC}

Means followed by, at least,one same letter, lowercase in the line and upper case in the column, for each variable, do not differ from each other by the tukey test ($p<0.05$).

temperatures reduces fruit respiration and consequently reduces losses of quality attributes such as color (Chitarra and Chitarra, 2005). Corrales-García et al. (2006) also studied the effect of storage temperatures and plastic coating in packaging on color alteration of minimally processed prickly pears, and the results showed that the smallest color alteration was obtained from the samples kept at 4ºC and coated by a 25 µm polypropylene layer.

The chromaticity of minimally processed prickly pears packaged with 11 µm PVC presented higher values when compared with other treatments stored at 6ºC (Table 2). However, among those stored at 3ºC, the PET treatment kept the highest values, followed by the 14 µm PVC coating. A similar behavior was also observed for the luminosity variable, which endorses the positive effect of the combination of low storage temperatures (3ºC) and PET packing on the maintenance of these two color attributes.

Storage temperatures had no influence on the SS content of minimally processed prickly pears (Table 3). At 6ºC, the tested packaging showed no differences. At 3ºC, fruits kept in PET packaging presented higher values than those in 14 µm PVC (Table 3). The difference among the values is minor, representing little or no influence of the different packaging and storage temperatures on the SS content. Piga et al. (2003) had also observed insignificant alteration of SS contents of minimally processed prickly pears stored in plastic trays coated with a polyolefin layer at 4ºC.

The decrease in carbohydrate reserves may reduce the organoleptic quality of some minimally processed products, for instance, the melon, in which quality is related to its sugar content (Brecht et al., 2007).

Fruits packaged with 14 µm PVC and PET kept higher acidity than those from other packaging, when stored at 3ºC (Table 3). At 6ºC, the PET lid treatment presented lower acidity than the others, but only a minor difference. This reduction may be due to the use of acids as a substrate in the respiratory process at a higher temperature (6ºC). This can be verified by analyzing the CO_2 concentration inside the packaging, which is found in higher accumulation inside the packaging stored at 6ºC compared with those at 3ºC, evidencing an increase in fruit respiration rate from samples stored at the highest temperature (Table 2).

Higher acidity contents were observed in fruits kept at 3ºC when compared with those kept at 6ºC (Table 3). This result suggests the effect of the 3ºC temperature is either on ripening reduction or fruit senescence delay. Piga et al. (2000) noticed an accentuated increase in the titratable acidity with a drastic decrease in the pH of minimally processed prickly pears, packaged in polystyrene coated with polyolefin layer, from the fourth storage day subjected to 15ºC, when compared with storage at 4ºC.

The ratio of soluble solids and titratable acidity was influenced by the packaging at 3ºC, where fruits kept in 14 µm PVC and PET showed lower values. However, when stored at 6ºC, an inverse situation was observed for both treatments, presenting the highest values for this variable (Table 3). Again, high storage temperature (6ºC) fomented an increase in fruit metabolism, indicated by a raise of SS values and reduction of TA (Table 3). Between the storage temperatures of 3 and 6ºC, there was a decrease in the SS/TA ratio that was caused by the rise of titratable acidity in the fruits.

Sarzi and Durigan (2002), while working with minimally processed 'Perola' pineapples, kept either in PET packaging or Styrofoam trays coated with PVC, noticed that at 9ºC the SS/TA fruit ratio presented higher values as a result of the reduction in acidity levels.

This experiment also observed the effects of PET treatments under 3ºC on fruit ripeness contention. Better maintenance of the organoleptic quality in products, was represented by the lower values of the ratio between soluble solids and titratable acidity (Table 3). The SS/TA ratio is an important quality parameter as it is indicative of taste, being one of the most used indexes to determine fruit ripeness and palatability (Mattiuz et al., 2003; Azzolini et al., 2004).

Regarding carotenoid contents, higher concentrations were found in fruits kept in PD 900 and 11 µm PVC, at 3°C when compared with those at 6ºC. When comparing the packaging methods, no difference in concentration was observed at 3ºC. At 6ºC fruits from the PET treatment with lid and 14 µm PVC obtained higher pigment

Table 4. Carotenoid content, appearance and color grades of minimally processed prickly pears stored under different temperatures and packaging for 12 days.

Packaging	Carotenoid (µg g^{-1})		Appearance (grades)		Color (grades)	
	6ºC	3ºC	6ºC	3ºC	6ºC	3ºC
PD 900	4.34^{bB}	6.23^{aA}	3.52^{aA}	3.21^{aB}	3.56^{aA}	3.34^{aB}
PVC 11 µm	5.25^{bAB}	6.31^{aA}	3.74^{aA}	3.5^{aAB}	3.69^{aA}	3.67^{aAB}
PVC 14 µm	5.89^{aA}	6.00^{aA}	3.53^{aA}	3.33^{aAB}	3.5^{aA}	3.43^{aAB}
PET	6.05^{aA}	6.17^{aA}	3.57^{aA}	3.7^{aA}	3.53^{aA}	3.78^{aA}

Means followed by, at least,one same letter, lowercase in the line and upper case in the column, for each variable, do not differ from each other by the Tukey test (P<0.05). Appearance and color grades: 5=excelent,4=good, 3=regular, 2=poor, 1=bad.

Table 5. Microbiological analysis, at the beginning, of minimally processed prickly pears stored under different temperatures and packaging.

Treatments	Mesophilic microorganisms (UFC/g)	Molds and yeasts (UFC/g)	Total coliforms at 45ºC NMP/g	Fecal coliforms at 45ºC NMP/g
PD 900 3ºC	30.0	<1.0×10²	<3.0	<3.0
PVC 11 µm 3ºC	20.0	1.8×10^4	<3.0	<3.0
PVC 14 µm 3ºC	2.7×10²	1.0×10²	<3.0	<3.0
PET 3ºC	60.0	2.0×10^3	<3.0	<3.0
PD 900 6 ºC	10.0	<1.0×10²	<3.0	<3.0
PVC 11 µm 6 ºC	2.3×10²	1.0×10²	<3.0	<3.0
PVC 14 µm 6 ºC	1.7×10^7	1.0×10²	<3.0	<3.0
PET 6 ºC	<10.0	<1.0×10²	<3.0	<3.0

UFC/g = colony forming units /g; NMP = most probable number/gram of prickly pear.

pigment values when compared with fruits in PD 900, indicating the outstanding influence of these treatments on the pigment maintenance (Table 4).

Carotenoids are compounds found in fruits and vegetables and, due to their role as antioxidants and the typical color pattern they grant to vegetables, the maintenance of these compounds is important to preserve the quality and nutritional characteristics of agricultural products (Brecht et al., 2007). Carotenoid concentrations are normally stable in non-climacteric fruits and vegetables after harvest, but also can be unstable when submitted to postharvest treatments and processing operations (Brecht et al., 2007).

Regarding the color and appearance attributes, the highest grades were given to the fruits stored in the PET packaging with lid at 3ºC, although they did not differ significantly from the ones kept in PVC packaging (Table 4). There was no influence from the different temperatures on the fruit appearance, except for those packaged in PD 900 that showed better grades under 6ºC (Table 4).

Analyzing the results for the color parameter separately, there was no significant difference between the studied temperatures; nonetheless, fruits packaged in PET with lid received the highest grade, 3.78 (Table 4). According to Damiani et al. (2008), among consumers and buyers, the appearance evaluation is the major factor in decision making on the intent to purchase a product.

In the present work, all treatments received an average grade of 3 (regular) regarding color and appearance parameters, but the fruits kept in PET at 3°C received slightly higher scores (3.78), indicating favorable attributes for consumption. Storage at 2°C for 12 days of minimally processed prickly pears maintained identical taste and smell of fresh fruits, according to sensory analysis (Añorve Morga et al., 2006).

Microbiological analysis, were realized at the beginning of the work (Table 5) and at the end of the work (Table 6), revealed that the samples presented values under 3MPN (most probable number/gram of prickly pear) of total and fecal coliforms at 45°C which were in accordance with the standards required by the Agência Nacional de Vigilância Sanitária (ANVISA, 2001).

Minimal processing may promote microbial growth in fruit, due exposure to nutrientes, upon the transfer of skin microflora to fruit flesh (Corbo et al., 2004). However, maintaining the sanity of fruits can be obtained by using good quality raw products, maintenance of proper sanitary conditions, control of relative humidity and temperature, and use of modified atmosphere packaging

Table 6. Microbiological analysis, at the end, of minimally processed prickly pears stored under different temperatures and packaging for 12 days.

Treatments	Mesophilic microorganisms (UFC/g)	Molds and yeasts (UFC/g)	Total coliforms at 45ºC NMP/g	Fecal coliforms at 45ºC NMP/g
PD 900 3ºC	<10.0	$<1.0\times10^2$	<3.0	<3.0
PVC 11 µm 3ºC	<10.0	$<1.0\times10^2$	<3.0	<3.0
PVC 14 µm 3ºC	30.0	$<1.0\times10^2$	<3.0	<3.0
PET 3 ºC	<10.0	$<1.0\times10^2$	<3.0	<3.0
PD 900 6ºC	1.4×10^2	7.0×10^2	<3.0	<3.0
PVC 11 µm 6ºC	5.6×10^2	5.0×10^2	<3.0	<3.0
PVC 14 µm 6ºC	3.4×10^2	8.0×10^2	<3.0	<3.0
PET 6 ºC	<10.0	3.5×10^3	<3.0	<3.0

UFC/g = colony forming units /g; NMP = most probable number/gram of prickly pear.

(King and Bolin, 1989; Nguyen-the and Carlin, 1994).

The Resolution RDC n° 12 of January 2nd 2001, has established maximum limits of 5×10^2 MPN of total coliforms for fresh, *in natura*, processed, sanitized, refrigerated or frozen fruits for direct consumption. The results confirm that good processing practices, allied with refrigeration, grant microbiological safety of products after preparation. Minimally processed prickly pears presented satisfactory visual and microbiological quality along 14 days under 4°C when stored in closed polypropylene microperfurated packaging (Goldman et al., 2005). According to Corbo et al. (2005) the storage of cactus-pear at temperatures greater than 4ºC can lead to a significant sanitary-risk and decrease shelf life.

Conclusions

Storage under 3°C associated with the PET packaging with lid provided the best results for quality maintenance of minimally processed prickly pears up to 12 days.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

Grant: 2010/03713-0, São Paulo Research Foundation (FAPESP).

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