Thermal Process Time and Sensory Evaluation for Canned Cactus Pear Nectar♦

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ABSTRACT

Cactus pear fruits have high nutritional value due to their high amounts of sugar and minerals. Cactus pear fruits were peeled and pulped in a pulping machine. The strained pulp was used to prepare cactus pear pulp and nectar. The obtained cactus pear pulp was used to produce canned cactus pear nectar, which was used to determine the heat resistance parameters of pectin methylesterase. The obtained D and Z values, $D_{100}^{37.5}$ = 1.85 min, were used to evaluate the thermal process of canned cactus pear nectar. Heating penetration curves for heating and cooling processes were calculated. Chemical properties and sensory characteristics of canned cactus pear nectar were determined.

Key words: Cactus pear pulp, nectar, pectin methylesterase, thermal process, sensory characteristics

INTRODUCTION

In Egypt, cactus pear has been grown since many years ago, especially in sandy areas in various parts of Egypt because it is extremely drought tolerant. The trees are grown not only for their fruits but also as fences and windbreaks or for erosion control in deforested areas (Abdel-Nabey, 2001). Fresh fruits are sensitive to chilling, and frequently show pits and dark spots upon cold storage below 10.3°C. Furthermore, both the low acidity and the high sugar content of the pulp make this fruit very susceptible to microbial invasion, thus limiting its storage life in the fresh state (Piga et al. 2000, Corbo et al 2004 and Cassano et al 2007). The presence of spines makes cactus pear difficult to peel. Minimal processing might be an important way to increase the acceptability of this fruit.

Cactus pear production in Egypt increased in recent years due to the increase in the producing area (from 618 hectares in 1994 to 1000 hectares in 2006). It is cultivated in many areas, such as Belbis, Sinai, Abo-Zabal and the reclaimed areas at El-Nubaria, El-Bostan, and Elbanger (Abdel-Nabey, 2001). The corresponding production increased from 10,233 tons in 1994 to 26341 tons in 2006 (MALR, 1994 and 2006).

Joubert (1993) found that in tests of processing five cultivars of cactus pear fruit, lye peeling was not effective because peel was partially removed and flesh erosion occurred. Pectin methyl esterase activity differed slightly between cultivars. It was in the range of 1.2-1.4 U/g. Saenz (2000) mentioned that cactus

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pear has become an important fruit crop in many semiarid lands of the world. The fruit and the young cladodes (nopalitos) commonly have been consumed fresh, but the last decade's research studies on cactus pear processing have produced another alternative that prevents damage to the fruit and, in spite of technological characteristics that make processing a challenge (high soluble solids content, low acidity and high pH), adds value to this crop. The results of several of these research studies involving the production of juices, marmalades, gels, liquid sweeteners, dehydrated foods, and other products are discussed. Sáenz and Sepúlveda (2001) present a review of cactus-pear juice production. Its technological characteristics are considered, as well as the main difficulties in obtaining high-quality juice. They showed that acidity, pigments, aroma, and other components play an important role in cactus pear juice processing. Goycoolea and Cárdenas (2003) presented a review on pectins from *Opuntia* spp. They reported that two distinctive water-soluble high-molecular-weight pectic polysaccharide materials that occur in *Opuntia* cladodes and fruits have been extracted and their chemical and rheological properties were studied, namely, the well-known mucilage and a calcium-sensitive gelling fraction. Matsuhiro et al. (2006) studied chemical characterization of the mucilage from fruits of *Opuntia ficus-indica*.

Piga (2004) mentioned that the constantly increasing demand for nutraceuticals is paralleled by a more pronounced request for natural ingredients and health-promoting foods. The multiple functional properties of cactus pear fit well this trend. Recent data revealed the high content of some chemical constituents, which can give added value to this fruit on a nutritional and technological functionality basis. High levels of betalains, taurine, calcium, magnesium, and antioxidants are noteworthy. Moßhammer et al. (2006) mentioned that crops with additional health-promoting and nutritional benefits, such as cactus pears, are increasingly gaining momentum both for health professionals and consumers. El-Samahy et al. (2006) collected orange-yellow cactus pear fruits from Egypt, called shameia variety, at the same ripening stage from different regions to evaluate selected chemical properties and to study the rheological behavior of their pulps. The results obtained showed that there were differences between the pulp characteristics, which may be due to environmental effects. The fruits showed pulp ratios of 41.53% to 49.63%. All pulps had low acidity and high pH values ranging between 0.049% to 0.057% and 6.00 to 6.20, respectively. El-Samahy et al. (2007) evaluated orange-yellow cactus pear pulp for some technological and chemical characteristics. The pulp was used to produce dehydrated cactus pulp sheet and pasteurized and sterilized cactus pear juices.

The thermal process is one of the main food preservation techniques, which intends to guarantee the product's final quality in terms of the consumer's health. The thermal sterilization of canned foods using retort equipment has been one of the most utilized preservation techniques for the last 200 years (Teixeira and Tucker, 1997). It is an important method of food preservation in the manufacture of shelf-stable canned foods and has been the cornerstone of the processed food industry for more than a century, (Simpson et al., 2007). However, over-processing must be avoided because thermal processes also have a detrimental effect on the quality (nutritional and sensorial factors) of foods. Therefore, the accuracy of the methods used for this purpose is of importance to food science and engineering professionals working in this field.

Time-temperature data are employed to evaluate the heat penetration parameters, f_h, j_{ch}, f_c, and j_{cc}, as well as to compute lethality and process time. The Ball's, Stumbo's, and Pham's methods are also utilized for calculating the process times and lethality (Afaghi et al., 2001).

The slow heating zone (SHZ) refers to a core region in the can that takes the longest time relative to the other regions to reach the final sterilization temperature and hence represents the rate limitation. Pflug (1987) defined the SHZ as the region in the food product that receives the least sterilization during the heat transfer process. In thermal processing it is important to provide adequate thermal treatment to the slowest heating zone and estimate its location with time in the food can. The slowest heating zone

analysis has been widely carried out in the literature for cylindrical cans (Datta and Teixeira, 1988; Ghani et al., 1999, 2002a, 2002b; Kumar et al., 1990; Kumar & Bhattacharya, 1991; Varma and Kannan, 2006).

The rate of heat penetration is measured by placing a thermocouple at the thermal center of a container to record the temperature of the food during sterilization, assuming that all other points in the container receive more heat and are, therefore, adequately processed. Fellows (1996) stated that in cylindrical containers, the thermal center is at the geometric center of the cylinder for conduction heated foods and approximately one third up from the base of the container for convection-heated foods. This is in agreement with the finding of Barbosa-Canovas et al. (1997), who also stated that the coldest point for a solid product would be at the center of the can, whereas in liquid-type products it is usually at a lower location. However, Al-Baali and Farid (2007) showed that in convection heating, the exact position of the slowest heating zone might change progressively.

The phrase "minimal thermal process" was introduced by the U.S. Food and Drug Administration in 1977 and it is defined as the application of heat to food, either before or after sealing in a hermetically sealed container, for a period of time and at a temperature scientifically determined to be adequate to ensure destruction of microorganisms of public health concern (Lopez, 1987).

The basic ideas of thermal process calculations are well presented in several published articles and textbooks (Ramaswamy et al., 1992; Yang and Rao, 1998; Ramaswamy and Marcotte 2006 and Toledo, 2007). It is important to note that there is a large amount of information about the formula method calculation and modification to suit a variety of equipments, techniques, and conditions of processing, especially in relation to estimation of thermal lags (Cleland and Robertson, 1985; Larkin, 1989; Larkin and Berry, 1991 and Hasahallis et al., 1997).

Pimienta (1990), Joubert (1993), and Sepúlveda and Sáenz (1990) reported that cactus pear fruit has high pH (5.3 to 7.1). So this fruit is classified within the low-acid group, (pH >4.5), requiring a thermal treatment of 115.5°C, or greater, to obtain good control of microorganisms. The pH, low acidity, and high soluble-solids content make cactus pear pulp a very attractive media for growth of microorganisms (Sepúlveda and Sáenz, 1990; Sáenz, 1995).

Previous studies identified a heat-resistant portion of pectinesterase (PME) and pectic enzymes in acidified pulp of papaya, which displayed greater thermal resistance than *Clostridium pasteurianum* in thermal destruction studies (Fayyaz et al., 1995 and Magalhaes et al. 1996, 1999). Also, Dastur et al. (1968) found that in high-acid foods the heat resistances of Lactobacilli, yeasts, and molds were lower than that of heat-resistant enzyme systems, such as peroxidase, pectin esterase, and polyphenol oxidase present in food that lead to undesirable changes unless inactivated. Pectinesterase (E.C. 3.1.1.11) is of prime importance to the food industry. It has a great impact on fruit and vegetable processing technology because of its potential effect on the quality of the finished products. It also plays a central role in the process of fruit softening during ripening; the control of its activity, through knowledge of its dependence on parameters such as temperature and pH, is of great practical importance for improving the texture of processed fruits and vegetables (Castaldo et al. (1989) and Fayyaz et al. (1995). Breakdown of pectin by PME destabilizes cloudiness of fruit juice if the juice does not receive sufficient heat treatment to inactivate PME (Pilnik and Voragen, 1991)**.** There are industrial processes where clarification of fruit juices is or is not required. For example, in citrus juice, the PME enzyme is usually inactivated by thermal treatment to prevent the clarification process (de Assis et al., 2001). In orange juice, PME (an undesirable enzyme) causes spoilage and cloud loss during storage. In addition, the enzyme is more heat resistant than spoilage microorganisms and, therefore, has been considered an index of the adequacy of pasteurization (Rahman, 2007).

Magalhaes et al. (1999) carried out heat-penetration trials on canned Formosa papaya pulp in order to study the kinetics of heat-resistant pectinesterase and to provide recommendations for commercial processing. Processing duration for the canned papaya (acidified to pH 3.8) was calculated using Shiga's method for estimating thermal process times for a given F value. A heating time of 12.9 min in a water bath at 97°C was established, which was equivalent to a 1.7 decimal reduction of the activity of heat-resistant pectinesterase (98% inactivation).

In Egypt, very little information on cactus pears is available in research papers and consumption as fresh fruits is limited. Thus, this study was planned to study the possibility of producing cactus pear nectar. In addition to analyzing chemical, sensory, and thermal properties of this product, D- and Z-values of pectin methylesterase enzyme were determined and effects of thermal processing were evaluated.

MATERIALS AND METHODS

Materials

Mature cactus pear fruits, yellow-orange, (*Opuntia ficus-indica*) were purchased from "El-Dair" village, Kaluobia governorate.

The cactus pear fruits were washed thoroughly in running water to remove the glochids (thorns), and then manually peeled with a knife. Peeled fruits were cut and pulped in a pulping machine to separate the seeds from pulp using the 1.0 mm (100 mesh) sieve. The pulp was pasteurized at 85°C for 3 min in double-jacket kettles and then cooled.

Preparation of cactus pear nectar

The cactus pear pulp, was diluted to 11.5°Brix, and then strained to remove undesirable particles; the total soluble solids in puree was 11.5°Brix. The typical formula of nectar was:

1 : 0.325 : 2 cactus pear pulp : sugar : water.

Citric acid solution 10% was added to adjust the nectar at pH 5. Nectar was heated to 85°C, poured into cans (Φ 65 x 110 mm), cans were sealed and thermal processed in a retort at 100.9°C and 110.2°C for 20 min.

The optimum thermal process of cactus pear nectar was evaluated on the basis of heat-resistance parameters of pectin methyl esterase (PME), which is considered to be the most resistant enzyme. Heat-penetration data were obtained for canned cactus pear nectar (Ø 65 X 110 mm), which was processed at 100.9°C and 110.2°C for 20 min. Heat penetration data were plotted as heating and cooling curves (Figure 3).

Analytical methods and measurements

Moisture, total solids, ash, and crude-fiber content were determined according to the methods described by the A.O.A.C. (1995). The total soluble solids and refractive index were measured at 20°C using an Abbe refractometer Model 1T at 20°C according to A.O.A.C. (1995). Total titratable acidity was determined according to Nielsen (1998) expressed as citric acid percentage. The pH values were measured using a Consort Model P107 pH meter. The formol titration obtained by means of a

potentiometer titration as described by Intoni et al. (1959). Ascorbic acid was determined using the 2,6-dichlorophenol indophenol dye titration method described by A.O.A.C. (1995). Total sugar and reducing sugar were determined by the method described in A.O.A.C. (1995), while nonreducing sugars were calculated by difference. Carotenoids were determined according to the method used by El-Mansy et al. (2000). Total pectic-substances were determined according to the method of Carre and Haynes, which was described by Kirk and Sawyer 1992. Color index was determined by the method of Meydow et al. (1977) as OD of cactus pear extract at a wavelength of 476 nm using one cm cell by a CE 599 Universal Automatic Scanning Spectrophotometer.

Degree of discoloration was determined according to the method described by Askar and Treptow (1993). Total petroleum ether-soluble and water-soluble color was measured. The petroleum ether-soluble color was a measure of the true carotenoid content of the sample. The water-soluble color gives an indication of the amount of browning reaction products formed during processing. The petroleum ether- and water-soluble fractions were extracted by shaking the sample in the presence of NN-dimethyl formamide (to give complete carotenoid extraction and cellular breakdown) and sodium chloride (to prevent the formation of emulsions). The color was measured spectrophotometrically and expressed as the extinction coefficient $E^{\%}_{cm}$.

$$E^{1\%}_{1\,cm} = 50\ A/TM$$

where: A = Absorption
T = Juice total solids in sample (%)
M = Mass of the sample (g)

Then, the degree of discoloration (Dd) was calculated from the extinction coefficients at 380 and 450 nm as follows:

$$Dd = \frac{E\ 380\ nm\ E^{1\%}_{1\,cm}}{E\ 450\ nm\ E^{1\%}_{1\,cm}}$$

Minerals were determined according to the McGary and Young (1976) method using a Perkin-Elmer Model 3100 Atomic Absorption Spectrophotometer. Phosphorus content was determined spectrophotometerically by the method described by Kirk et al. (1987).

Determination of pectin methylesterase activity

Pectin methylesterase activity was evaluated according to the method used by Carbonell et al. (2006) with slight modification as follows:

Into a 250 ml beaker, 50 g of juice was weighed accurately and 50 ml of pectin solution 1% containing 0.1 N sodium chloride was added. The substrate and juice sample was mechanically stirred in the beaker and rapidly titrated to pH 7.5 with 0.2 N sodium hydroxide. The beaker was placed in a water bath at 30°C and the reaction began as soon as the pH was adjusted to 7.5 by NaOH through a reaction period of 30 min.

Pectin methylesterase units were expressed by the symbols (PME U/g juice), which represent the milliequivalent of ester hydrolyzed per min per g of juice.

The equation used for computing pectin methylesterase units per juice was:

$$\text{PME U/g juice} = \frac{\text{ml NaOH x Normality}}{\text{Weight of sample x 30 min}} \text{ x } 103$$

Thermostability of PME enzyme

To study the thermostability of the tested PME enzyme of cactus pear nectar, 50 mL of cactus pear nectar were placed in Nessler test tube (3 replicates). The tubes were completely immersed in a water bath at various temperatures (75-110°C) and were held for different periods (0-5 minutes), the time was calculated after reaching the examined temperature. The tubes were then cooled in tap water to room temperature. The residual activity of pectin methyl esterase enzyme was measured immediately.

Decimal reduction time (D-value) is the time in minutes required to inactivate 90% of the enzymes under investigation. Thermal destruction curves were obtained by plotting the log of percent residual activity against treatment time for different temperatures; linear trend lines were obtained using Microsoft Office 2000 Excel. Reciprocals of slopes of the obtained trend lines were calculated, which equal D-values. The obtained D-values were used to calculate Z-value. The Z-value was the rise in temperature (°C) necessary to observe a ten times faster heat inactivation or to reduce the D-values to 1/10 (90% reduction in D-values). So, log of D-values were plotted against temperature and reciprocal's slope of linear trend line was calculated, which equal Z-value

Estimation of slowest heating point inside cans

It is important to check the slowest heating point inside the cans for a product to obtain the actual F-value. Three copper-constantan thermocouples of the self-made type T were mounted on the central axis of the can (size Ø 65 X 110 mm) at three different heights above bottom. The heights were ¼, 1/3, and ½ can height (i.e., 28, 42, and 56 mm, respectively). Rubber stoppers held the thermocouples in place. The replicates were 3 cans.

Evaluation of thermal process of cactus pear nectar

Heat penetration data, at slowest heating point, were obtained using a Yokogawa Recorder, Model 3081, hybrid recorder with 30 channels. Heating and cooling curves were plotted according to Ramaswamy and Marcotte (2006).

Heat penetration data (dimensionless temperature against processing time) were plotted as heating and cooling curves. Reciprocal's slope of the straight-line portion was calculated, which equal f_h and f_c values for heating and cooling phases of canned cactus pear nectar, respectively. Heating and cooling curves parameters were used to evaluate the thermal process times for canned cactus pear nectar. Calculation of F value was based on Z- and D-values at 100°C reference temperature of pectin methylesterase (PME) enzyme:

$$D_{100}^{37.5} = 1.85 \text{ min}$$

The following steps were carried out to evaluate thermal process of cactus pear nectar (Sleeth, 1978):

1- Equation (1) was used to obtain g value.

$$B = f_h (\log J_h I_h - \log g) \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$J_h = (T_r - T_{pih})/I_h \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where:

B: Thermal process time corrected for time required to bring the retort to processing temperature.

f_h: Number of minutes required to cross the straight-line portion of the heating curve one log cycle.

T_r: Retort or process temperature.

T_{pih}: Pseudo-initial food temperature when heating is started. Temperature indicated by the intersection of the extension of the straight-line portion of the heating curve and a vertical-line representing beginning of heating that zero time is shifted 0.58 l.

I_h: T_r - T_{ih} (Difference between retort temperature and food temperature when heating is started.)

T_{ih}: Initial food temperature when heating is started.

g: Difference in degrees Fahrenheit between retort temperature and the maximum temperature reached by the food at the point of concern.

l: Time, in minutes, required to bring retort to processing temperature (come-up time).

2- From Non (1968), using Figures (9-4 and 9-5 on pages 232–233, the f_h/U: log g was obtained using (m+g) values of =54.4°C (130°F) or 71.1°C (160°F) and a new curve was plotted in the figure with new Z = 37.5°C (67.5°F) to calculate f_h/U: log g. Then, U could be obtained by substituting for f_h.

3- F_i value was calculated by the following equation:

$$F_i = \text{log-1}\ (T_x - T_r/Z) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

4- From the following equation F could be calculated:

$$U = FF_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

5- Using the following equation, percent enzyme activity retained, b, could be calculated:

$$F = D_r (\log a - \log b) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where:

(m+g): Difference between retort temperature and cooling-water temperature.

U: The equivalent in minutes at retort temperature of all lethal heat received by some designated point in the container during the process.

F_i: Time at any other temperature equivalent to 1 minute at some designated reference temperature.

T_x: Reference temperature.

T_r: Retort temperature.

Z: Number of centigrade degrees required for the thermal destruction curve (for pectin methylestrase enzyme) to traverse one log cycle.

F: The equivalent, in minutes, at some given reference temperature (100°C), of all heating considered with respect to its capacity to destroy spores, vegetative cells of a particular organism, or enzyme.

D_r: Time required at any designated reference temperature (100°C) to destroy 90% of the spores, vegetative cells of a given organism, or destroy 90% of activation of a given enzyme.

a: Initial percentage of enzyme activity.

b: Final percentage of enzyme activity retained at end of process.

Temperature conversion for different initial temperatures

According to Schultz and Olsen (1940), mentioned by Holdsworth (1997) and Sharoba, et al. (2007), the equation for converting food (can) temperature when the retort temperature remained the same, is:

$$Tc' = Tr - \frac{Tr - Ti'}{Tr - Ti}(Tr - Tc) \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where:

T_r: retort temperature.
T_i`: new initial temperature.
T_i: original initial temperature.
T_c: a can temperature of the original set.
T_c`: a new can temperature corresponding to Ti`.

Sensory evaluation

Sensory evaluations of pear nectar, fresh or processed, were carried out by 10 panelists, Panelists were asked to evaluate color, odor, taste, mouth feel, and texture for cactus pear nectar. The maximum score for each attribute was 10. While the overall acceptability attributes were 50 scores.

Statistical analysis

Data of sensory evaluation are presented as means and 95% confidence intervals of the individual treatments. Analysis of variance for sensory evaluation data was carried out using Microsoft Office 2000 Excel.

RESULTS AND DISCUSSION

Chemical composition of cactus pear pulp

Table 1 shows chemical composition of raw cactus pear pulp.

The total solids and total soluble solids contents are important factors in the production of fruit juice. It is well established that the higher the total solids, the better is the quality of juice. These results are in agreement with Askar and Elsamahy (1981) and Sepulveda and Saenz (1990). They found that the total solids content was 10.23 to 14.06°Brix, while the results of Pimienta (1990) ranged from 12 to 17°Brix of cactus pear juice. The difference between the results is related to many factors, such as variety and environment.

Titratable acidity and pH value would be of great importance because the ratio of total soluble solids to acidity will affect flavor. In the same table, data showed that titratable acidity was 0.072% (as citric acid) and pH was 5.72; and it is known that the cactus pear juice had high pH value and these attributes place the product in the low-acid food group. The obtained results agree with Sawaya et al. (1983) and Sepulveda and Saenz (1990). On the other hand, Joubert (1993) reported titratable acidity 0.02 to 0.03% as citric acid and pH values 6.13-6.38.

Sugars were the major soluble solids of the cactus pear fruits. Total, reducing sugars, and nonreducing sugars of cactus pear pulp, were 10.86, 10.75, and 0.11%, respectively. These results were in agreement with Sawaya et al. (1983) and El-Samahy et al. (2006). They found that total sugars were in the range from 10.5 to 12.8% fresh weight. Also, Singh and Felker (1998) found that the reducing sugars were 11.8% (glucose 7% and fructose 4.8%) while the nonreducing sugar was 0.2% sucrose. Joubert (1993) reported total sugars of 8.26 to 11.54%.

Ascorbic acid retention is a good indicator of high food quality because of its nutritional value. In addition, it has a high nutritive value, being one of the important vitamins. As shown in Table 1, ascorbic acid (Vitamin C) content was 13.70 mg/100 g in the raw cactus pear juice. These results agree with Soliman (1996). Also, Kuti (2004) reported that Vitamin C in *Opuntia lindheimer* was 12.1 mg/100 g (121 µg/g) of fresh weight. Singh and Felker (1998) reported a high value of 22 mg/100 g. However, cactus pears have a high level of ascorbic acid, which can reach levels near 40 mg/100 g (Pimienta, 1990; Sepúlveda and Sáenz, 1990; Rodriguez et al., 1996).

Carotenoids content was 0.83 mg/100 g. This result agrees with Sepulveda and Saenz (1990), who reported a carotenoid content of 0.53 mg/kg.

Total pectic substances, water-soluble pectin, ammonium oxalate-soluble pectin, and acid-soluble pectin were 0.49, 0.11, 0.31, and 0.07% for raw cactus pear pulp, respectively. The result was higher than that reported by Sepulveda and Saenz (1990) and Sawaya et al. (1983). They reported that pectin ranged from 0.17 to 0.19%. Also, El-Samahy et al. (2006) found that total pectin was 2.24 to 2.74% on dry-weight basis.

In the same table, the sugar/acid ratio was 150.83 for the cactus pear pulp. Joubert (1993) reported sugar/acid ratios of 280 to 490.

With respect to the mineral content of raw cactus pear pulp, data showed that calcium (Ca) was 333.0 mg/kg, magnesium (Mg) 183.6 mg/kg, phosphorus (P) 134.9 mg/kg, sodium (Na) 80.3 mg/kg, potassium (K) 838.9 mg/kg, iron (Fe) 6.43 mg/kg, and copper (Cu) 0.184 mg/kg of raw cactus pear pulp. These results agree with the results recorded by Watt and Merrill (1975), Sawaya et al. (1983), Askar and El-Samahy (1981), and Singh and Felker (1998).

Determination of D-values and Z-value of pectin methylesterase for cactus pear nectar at modified pH value (5.0)

To give a definition for heat stability of PME enzyme of cactus pear, the D-values and Z-value of the PME enzyme were calculated. Reciprocal's slopes of the obtained trend lines (Figure 1) were calculated, which equal D-values. As shown in Table 2, the D-values of pectin methylesterase of cactus pear nectar at pH 5.0 were 9.55, 4.73, 3.85, 1.85, and 1.08 min at 75, 85, 95, 100, and 110°C, where the correlation coefficients (R) were 0.8981, 0.9645, 0.8370, 0.9293, and 0.9464, respectively.

Reciprocal's slope of linear trend line (Figure 2) was calculated, which equals Z-value. The Z-value of PME enzyme was 37.50°C with correlation coefficient (R) of 0.9496. There are no available data in the literature about pectinmethylestrase of cactus. However, this result was higher than the Z-value estimated by Laratta et al. (1995) for three pectinesterase isoenzymes (PME1, PME2, and PME3), which were purified from tomatoes. This may be due to the high acidity and low pH of tomatoes. The Z-values were 24°C for PME1 and PME3, while PME2 had a Z-value of 15°C. Also, Labib (1992) determined the D-values and Z-value for pectin methylesterase of mango and found that D-values were 8.0 min at 75°C and 2.5 min at 85°C with the Z-value of 18.5°C for PME.

Evaluation of thermal process of cactus pear nectar

Figure 3 shows heat-penetration data for canned cactus pear nectar (Ø 65 110 mm) which was processed at 100.9°C and 110.2°C for 20 min. Reciprocal's slope of the straight-line portion for heating and cooling phases was calculated, which equal f_h and f_c values of canned cactus pear nectar, respectively. The f_h and f_c values were obtained and tabulated in Table 3. Data indicated that increasing retort temperature from 100.9°C to 110.2°C was accompanied by decreasing the f_h value from 8.07 to 4.52 min for the heating phase, respectively. On the other hand, increasing retort temperature from 100.9°C to 110.2°C was accompanied by increasing f_c from 9.17 to 9.51 min for cooling phase for canned cactus pear nectar, respectively. Also, the j_h were 1.19 and 1.28 for thermal processing at 100.9 and 110.2°C/20 min, respectively (Equation 2).

Heating and cooling curves parameters were used to evaluate the thermal process as indicated in Table 3. It could be seen that thermal process time of 20 min holding at 100.9°C and 110.2°C (after come-up times of 5.0 and 6.0 min, respectively) resulted in F values of 17.41 and 38.33 min, respectively, for canned cactus pear nectar. Calculation of F-values was based on Z- and D-values of pectin methylesterase (PME) enzyme at 100°C reference temperature.

As shown in Table 3, the percentage of enzyme retention was 3.88×10^{-8} and 1.91×10^{-19}, which means no retained enzyme activity for the process of 100.9°C/20 min and 110.2°C/20 min, respectively.

The decimal reduction of enzyme equivalent to F-value used for process calculation (F/D) was 9.41 and 20.72 for the two processes, respectively.

To illustrate the effect of initial temperature of cactus pear nectar on a verified F-value, the obtained heat penetration data were converted to obtain new data at a new initial temperature using equation (6). So, the new calculations are presented in Table 4. Comparing data of Tables 3 and 4 indicated that increasing the initial temperature is accompanied by increasing the verified F-values. For example, processing of cactus pear nectar at 100.9°C for 20 min, at initial temperatures 28°C and 50°C, was accompanied by F-values of 17.41 and 19.13, respectively. Also, processing of cactus pear nectar at 110.2°C for 20 min at initial temperatures of 29 and 50°C, was accompanied by F-values of 38.33 and 40.47 min, respectively.

Effect of canning process on some chemical properties of cactus pear nectar

Table 6 shows some chemical properties of canned cactus pear nectar heat processed at 100.9 and 110.2°C for 20 min. Data indicated that thermal processing has a major effect on ascorbic acid (Vitamin C), Color index (O.D. at 476 nm), and carotenoids contents of canned cactus pear nectar. It could be stated that the preheating had high effect on the ascorbic acid content, while the thermal process had no marked effect on it. This may be attributed to the fact that the preheating was done in an open vessel exposed to the air, which caused the oxidation of ascorbic acid. In addition, it may be also due to the complete inhibition of ascorbic acid oxidase by the thermal process. Ahmed (2000) reported that the thermal process decreased ascorbic acid content of canned nectar. Decreasing color index value may be due to the effect of severe treatment on the pigments of cactus pear (Dradak and Vallova, 1990 and Delgada-Vargas et al., 2000). Reduction of carotenoids content may be due the effect of heat treatments.

The carotenoids content in cactus pear nectar was 0.341 and 0.302 mg/kg for prepared (raw) and after preheating (PPN), respectively. After processing at 100.9°C/20 min and 110.2°C/min, the values were 0.241 and 0.210 mg/kg, respectively. Reduction of carotenoids content may be due the effect of heat treatments.

Sensory evaluation for canned cactus pear nectar

The canned cactus pear nectars before processing, processed at 100.9°C/20 min, and processed at 110.2°C/20 min, were evaluated for taste, odor, color, mouth feel, appearance, and overall acceptability. The data are recorded in Table 5. Analysis of variance for these data showed that there are significant differences between all attributes of raw cactus pear nectar and the processed samples either at 100.9°C/20 min and/or 110.2°C/20 min. The highest score values in taste, odor, color, mouth feel, appearance, and overall acceptability were 9.3, 8.9, 9.0, 8.8, 8.95, and 47.8 degree, respectively, for raw cactus pear nectar, while the lower score values in all attributes were for cactus pear nectar processed at 110.2°C/20 min.

On the other hand, the cactus pear nectar processed at 100.9°C/20 min had intermediate score values in all the attributes. These scores were nearly higher than cactus pear, which processed at 110.2°C/20 min.

Finally, the cactus pear nectar processed at 110.2°C for 20 min was not accepted in taste, color, odor, and mouth feel. So, using 100.9°C/20 min during thermal processing of cactus pear nectar should avoid any effect on the quality.

Untabulated data of incubation test of cactus pear nectar indicated that process (100.9°C/20 min) was suitable for the product. Also, neither gas was formed (flat) in cans nor was the pH value of the product changed. So, the product took a suitable thermal treatment for inactivation of PME enzyme that agrees with the thermal process evaluation (Table 3). The product had an F-value for PME of 17.41 min and the percentage of enzyme retention was 3.88 x 10-8 after 20 min at 100.9ºC, i.e., no retained enzyme activity. It is concluded that using 100.9°C/20 min during thermal processing of cactus pear nectar will avoid any effect on the quality.

CONCLUSION

Determination of optimum thermal process time for canned foods is very important to save energy and to keep quality of the products. In spite of cactus pear fruit being classified within the low-acid group (pH >4.5), requiring a thermal treatment of 115.5°C, cactus pear nectar is proved to be thermally processed at 100.9°C/20 min.

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Table 1. Chemical composition of cactus pear pulp*.
(Data was calculated on fresh-weight basis.)

Component	**Cactus Pear Pulp**
Moisture (%)	86.79
Total solids (%)	13.21
Total soluble solids (°Brix)	11.53
Acidity (as citric acid) (%)	0.072
pH value	5.72
Total sugar (%)	10.86
Reducing sugar (%)	10.75
Nonreducing sugar (%)	0.11
Sugar/acid ratio	150.83
Ascorbic acid (vitamin C) (mg/100 g)	13.70
Carotenoides as β-carotene (mg/100 g)	0.83
Total pectic substance (%)	0.49
Water soluble pectin (%)	0.11
Ammonium oxalate soluble pectin (%)	0.31
Acid soluble pectin (%)	0.07
Sugar/acid (ratio)	150.83
Crude fiber (%)	0.38
Color index (O.D. at 476 nm)	1.902
Degree of discoloration ($E_{cm}^{\%}$).	16.98
Refractive index at 20°C	1.3515
Formol number (mlequ./100 g)	24.30
Ash (%)	0.34
Minerals Content	
Calcium (Ca) (mg/kg)	333.0
Magnesium (Mg) (mg/kg)	183.6
Phosphorus (P) (mg/kg)	134.9
Sodium (Na) (mg/kg)	80.3
Potassium (K) (mg/kg)	838.9
Iron (Fe) (mg/kg)	6.43
Copper (Cu) (mg/kg)	0.184

Table 2. D-values and Z-value for the pectin methylesterase of cactus pear nectar at pH 5.0.

Temperature (°C)	D-values (min)	Correlation Coefficient (R)
	Cactus Pear Nectar	
75	9.55	0.90
85	4.73	0.96
95	3.85	0.84
100	1.85	0.93
110	1.08	0.95
Z-value in °C	37.50	0.95

Table 3. Evaluation of the carried out thermal process times as enzyme activity retention for cactus pear nectar in cans (Ø 65 x 110 mm).

Thermal Processing Parameters	Canned Cactus Pear Nectar Process at	
	100.9°C/20 min (A)	110.2°C/20 min (B)
Retort temperature (°C)	100.9	110.2
Come-up time (C.U.T) (min)	5.0	6.0
Holding time (min)	20.0	20.0
Initial temperature (°C)	28.0	29.0
f_h (min)	8.07	4.52
f_c (min)	9.17	9.51
J_h	1.19	1.28
J_c	2.01	1.65
Z-value (°C)	37.50	37.50
Reference temperature (°C)	100.00	100.00
D-value of P.M.E	1.85	1.85
F-value for process	17.41	38.33
Decimal reduction of enzyme equivalent to F value used for process calculation (F/D) (sterilization value)	9.41	20.72
% of enzyme retention	3.88×10^{-8}	1.91×10^{-19}

Table 4. Evaluation of thermal process times as percent enzyme activity retention for cactus pear nectar in cans (Ø 65x110 mm) at constant initial temperature 50°C.

Thermal Processing Parameters	Canned Cactus Pear Nectar Process at	
	100.9°C/20 min (A)	110.2°C/20 min (B)
Retort temperature (°C)	100.9	110.2
Come-up time (C.U.T) (min)	5.0	6.0
Holding time min.	20.0	20
Initial temperature (°C)	50.0	50.0
f_h (min)	7.24	4.23
f_c (min)	9.17	9.51
J_h	1.4	1.64
J_c	1.9	1.65
Z-value (°C)	37.50	37.50
Reference temperature (°C)	100.00	100.00
D-value of P.M.E	1.85	1.85
F-value for process	19.13	40.47
Decimal reduction of enzyme equivalent to F-value used for process calculation (F/D) (sterilization value)	10.34	21.88
% of enzyme retention	4.57×10^{-9}	1.33×10^{-20}

Table 5. Sensory evaluation of canned cactus pear nectar processed at different temperatures. (95 % Confidence Interval, Mean of 10 panelists ± standard error)

Treatments	Taste (10)	Odor (10)	Color (10)	Mouth Feel (10)	Appearance (10)	Overall Acceptability (50)
Fresh cactus pear nectar	9.30 ±0.58	8.90 ±0.51	9.00 ±0.58	8.80 ±0.65	8.95 ±0.51	47.80 ±1.23
Canned cactus pear nectar processed at 100.9°C for 20 min	6.50 ±0.82	6.55 ±1.4	7.20 ±0.56	6.10 ±0.91	6.70 ±0.62	37.50 ±2.9
Canned cactus pear nectar processed at 110.2°C for 20 min	4.75 ±1.09	5.00 ±0.87	5.55 ±1.09	5.00 ±0.74	6.00 ±1.18	27.80 ±2.85

Table 6. Effect of canning process on some chemical properties of cactus pear nectar (means ± SE)*.

Properties	Raw Cactus Pear Nectar	Preheated Cactus Pear Nectar	Processed Cactus Pear Nectar at	
			100.9°C/20 min	110.2°C/20 min
Total solids (%)	16.37±0.05	17.04±0.01	17.17±0.01	17.02±0.01
Soluble solids (^{o}Brix)	15.18 ±0.01	15.95 ±0.03	16.03 ±0.01	15.90 ±0.04
Acidity (as citric acid) (%)	0.089 ±0.001	0.097 ±0.001	0.10 ±0.01	0.11 ±0.003
pH value	5.00	4.92	4.98	4.96
Ascorbic acid (mg/100 g)	3.72 ±0.07	2.24 ±0.04	2.13 ±0.01	2.08 ±0.02
Total sugars (%)	14.40 ±0.07	14.77 ±0.09	14.79 ±0.06	14.75 ±0.02
Reducing sugars (%)	3.32 ±0.10	3.92 ±0.04	4.80 ±0.04	4.88 ±0.07
Nonreducing sugar (%)	11.08 ±0.13	10.85 ±0.04	9.99 ±0.07	9.87 ±0.01
Color index (O.D. at 476 nm)	0.601 ±0.001	0.541 ±0.02	0.505 ±0.003	0.460 ±0.02
Formol number (mleq/100 ml)	6.61 ±0.13	6.36 ±0.10	6.33 ±0.05	6.26 ±0.07
Carotenoids as β-carotene (mg/kg)	0.341 ±0.02	0.302 ±0.003	0.241 ±0.004	0.210 ±0.003

* Data calculated on wet-weight basis.

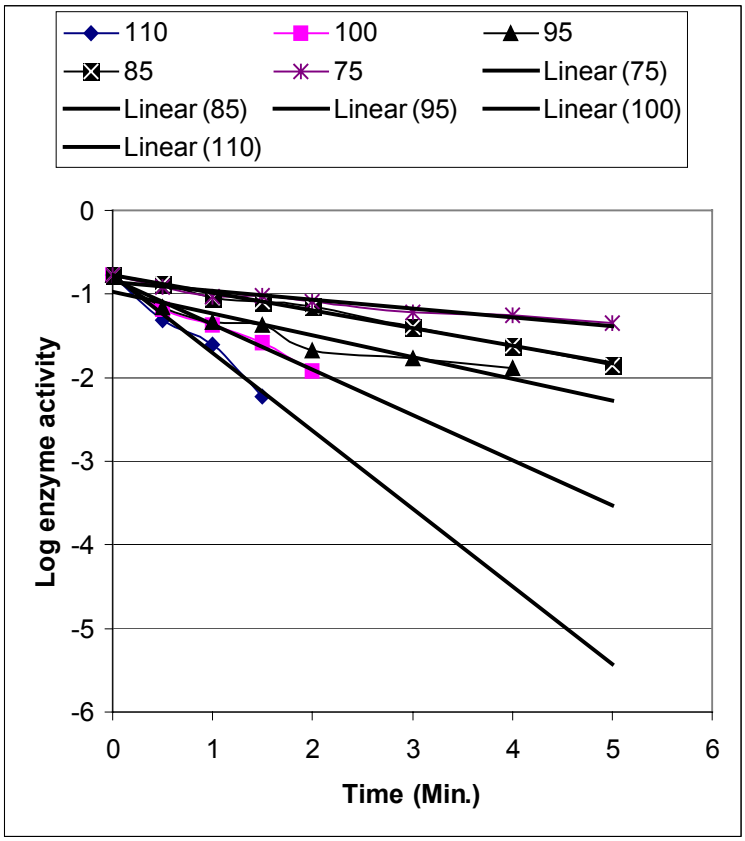


Figure 1. Thermal destruction curves to determine D-values for pectin methylesterase enzyme.

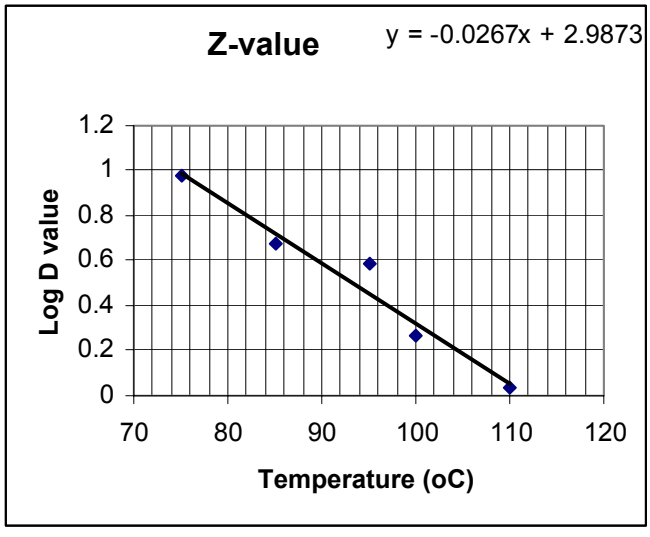
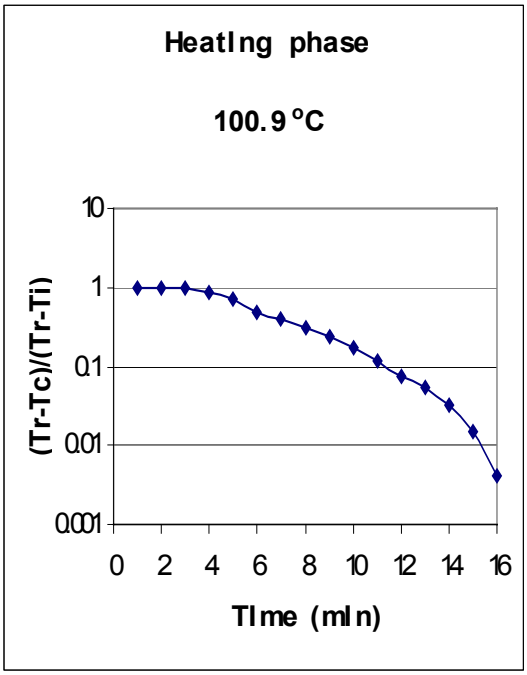
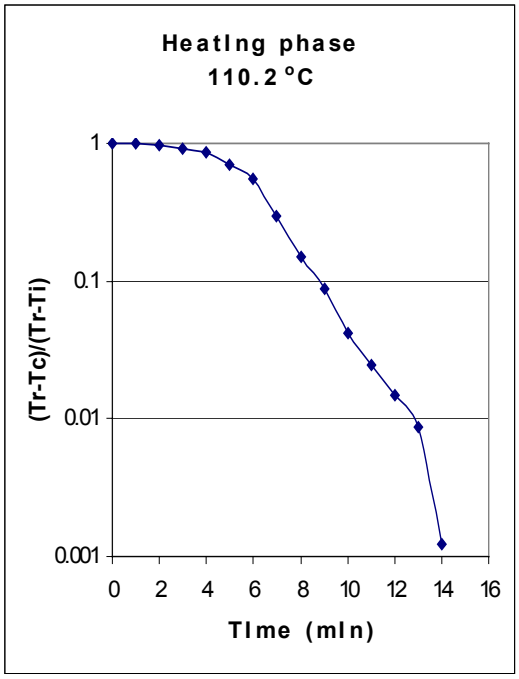
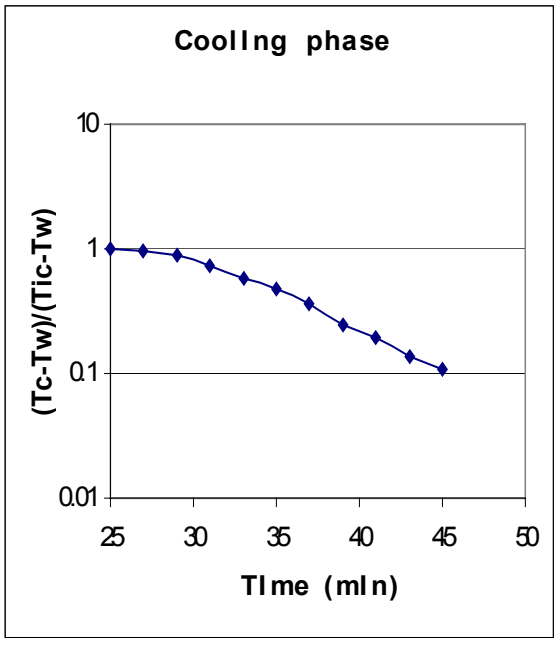


Figure 2. D vs temperature to determine the Z-value for pectin methylesterase enzyme.







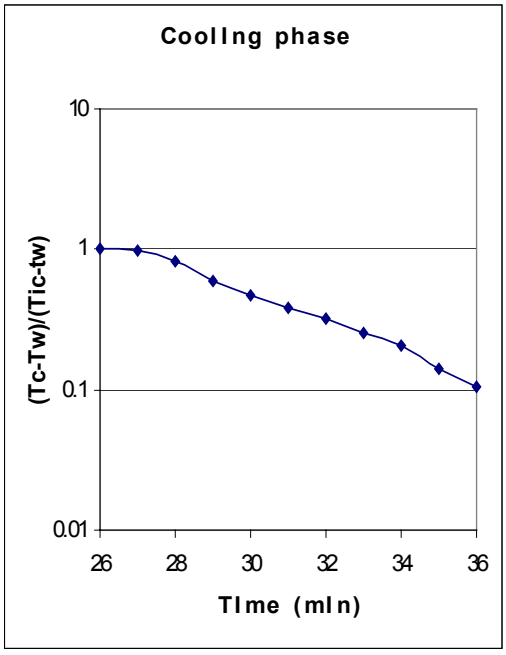


Figure 3. Heating penetration curves for cactus pear nectar (Ø 65 x 110 mm) thermally processed at 100.9°C and 110.2°C for 20 min.