Effects of enzymatic treatment on the chemical composition, antioxidant and rheological properties of cactus cladode juice

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Abstract. Cactus (Opuntia ficus-indica), commonly referred as prickly pear or nopal cactus, belongs to the family Cactaceae. It has attracted domestic and international industries’ attention owing to its nutritional and health benefit potentials. In this project, the quality of the cactus cladode juice after treated with the enzymes Pectinex Ultra SP-L and Viscozyme was investigated in terms of total phenolic content (TPC) and 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging activity. There were significant increases in the effectiveness of these enzymes as the concentration increased from 0.05 to 0.15% w/w. Among different concentrations, 0.15% w/w produced a higher yield and high-quality juice. Furthermore, the result indicates that prolonging the incubation duration could improve juice yield but this occurred only within the first hour of reaction, which the highest yield was obtained at 0.75 h. At these conditions, the combination of Pectinex Ultra SP-L and Viscozyme at ratio 1:1 (w/w) showed the most effective on juice yield improvement and 2,2-diphenyl-1-picrylhydrazyl free radical scavenging activity, while the highest total phenolic content was obtained when treating with Pectinex Ultra SP-L. Particularly as compared to the control sample, the juice yield increased from 53% to 76%, the TPC enhanced from 47 g gallic acid equivalent (GAE)/mL to 70 g GAE/mL, and the DPPH free radical scavenging activity improved from 277 g ascorbic acid equivalent (AAE)/mL to 470 g AAE/mL. Overall, the quality of cactus juice was better with enzymatic treatment than that of the untreated juice. The data also showed that the cactus juice behaved as shear–thickening fluids at room temperature.

1. Introduction

Nopal cactus or prickly pear, which has the scientific name Opuntia spp., belongs to the dicotyledonous angiosperm Cactaceae family [1]. Based on high ecological adaptability, it is widely grown in tropical and subtropical zones such as South Africa, Latin America, and the Mediterranean regions [2]. In Morocco, this plant can be classified in three types. "Christian nopal", so-called prickly cladode, is used for field fences while "Muslims' nopal" (inermis cladode) is used as cattle feed. Another type is “Moses’ nopal” with large inermis cladodes. The term “cladode” is used to describe the flattened stem of cactus...
that is also called cactus pads, cactus vegetable or phylloclades [3]. They are thin with strong green color and can be cut for use when their length reaches 15 – 20 cm.

For general compounds, the cactus cladodes are rich in vitamins, minerals, antioxidants and various flavonoids [1]. Numerous previous studies show that the health benefits of \textit{Opuntia} cactus such as antioxidant activity come from their polyphenols, especially quercetin 3-methyl ether [4, 5]. Furthermore, the high amount of nicotiflorin (146.5 mg/100 g) found in stems was reported as an active agent in neuroprotective mechanism against the cerebral ischemia disease [6]. The compound not only reduces memory dysfunction, but also has function on energy metabolism failure and oxidative stress. In addition, cladodes contain 2.35 – 55.20 mg potassium and 5.64 – 17.95 mg calcium per 100 g dry weight, which can help to reduce blood pressure in hypertension-suffered patients [7]. The lyophilized cladode and fruit extracts were also proved to have anti-inflammatory activity [5].

In Mexico, \textit{Opuntia} cactus has been traditionally used as folk medicine to cure burns, wounds, edema, and indigestion [5]. It also is demonstrated to have good effects on ulcers, allergies, fatigue and rheumatism. Nowadays, similar to green beans, the cladodes are served as vegetables and salad with meals [3]. Cactus cladodes may contain certain anti-nutrients such as oxalates. However, their reported amount was lower than the limiting intake for human [8]. Moreover, cladode pulps are also used for cosmetic products, for instance shampoos, conditioners, face and body lotions, soaps, hair gels and sun protectors [9].

In Vietnam, nopal cactus is planted mostly in the central area, for example Binh Thuan, Ninh Thuan, Quang Ngai, Hue, etc. However, it is not popularly used as food in the country. Therefore, it is practical to develop new cactus products and juice is one of popular choice. Many processes of juice manufacturing utilize enzymes with the purposes of higher juice yield and clarity, in which pectinolytic and cellulolytic enzymes are mainly used. The previous study demonstrated that enzymatic treatment could affect positively on physico-chemical and antioxidant properties of blueberry juice [10]. Specifically, the addition of enzymes resulted in increased juice yield and total anthocyanins. These enzymes are usually used in two main stages. First, they are added after crushing to complete liquefaction, which aids to obtain more juice with more highly valuable components. Also, enzymes are used after juice extraction to clarify juice and reduce viscosity [11].

In making juice, enzymatic treatment is one of the most important step, that affects the quality and nutrition values of the juice [12]. Addition of commercial enzymes not only increases the yield and nutritional value of juice, but also decreases its viscosity. In the research, the type of enzymes also influences the parameters of juice such as turbidity, yield and viscosity. To be specific, pectinase was reported to be more effective and result to higher yield than cellulase in certain cases. Moreover, enzyme treatment also helped to improve antioxidant activity in juice. The study showed that the higher enzyme concentration, the higher total antioxidant activity. It can be said that the concentration of enzyme is one of the crucial factors that modify the properties of juice. Another factor that will be investigated is treatment duration. The time during enzyme – assisted process may impact on the juice yield or antioxidant properties. As a result, the types of commercial enzymes at different concentrations and treatment durations should be studied to obtain the optimum conditions for enzymatic treatment. Particularly, Pectinex Ultra SP-L and Viscozyme L will be used. Pectinex Ultra SP-L has been reported to have high activities of pectinase, xylanase and cellulase [13] while a complex mixture of numerous enzymes including xylanase, cellulase, hemicellulase, arabanase and beta-glucanase has been indentified in Viscozyme L [14]. These enzymes have widely been used in juice processing. Through this study, the process of making cladode juice from nopal cactus, which contains high antioxidant properties can be
established. Also, informative databases of physiochemical and antioxidant characteristics of the juice will be provided.

2. Materials and methods

2.1. Materials
Fresh cactus cladodes (Opuntia ficus indica) were obtained from Binh Thuan province (Vietnam) in July. The used enzymes were Pectinex Ultra SP-L and Viscozyme L, which belong to Novozymes purchased from local distributors. They had the declared activities of 100 FBG/g and 3300 PGNU/g, respectively. Other chemicals were purchased from local distributors.

2.2. Sample preparation
After harvesting cacti, their thorns were cut moderately for the ease of transport. To preserve and prevent dehydration, the cacti was kept in zip bags before put in cool boxes. After transferred to the laboratory, their thorns were removed and the cladodes were washed carefully. Next for the ease of blending, the cacti were cut into small cubes. After blending, the pulp was well mixed before separating it into small bags and storing it at freeze temperature. Before used in next step, the cactus pulp was thawed and mixed with water at the 1:1 w/w ratio.

2.3. Enzymatic treatment and juice preparation
The cactus pulp was mixed with a certain enzyme (i.e. Pectinex, Viscozyme or their 1:1 w/w mixture) at different concentrations (0%, 0.05%, 0.1%, 0.15% and 0.2%). Then, the mixtures were incubated in a water bath at 45°C for 1 h. The pH should be adjusted by using the citric acid solution to 4.5, which was the suitable pH for the activities of both enzymes [15]. After that, the samples were heated at 100°C for 5 minutes to inactivate the enzymes. They were then rapidly cooled down to 25°C before centrifuging. After that, the clarified samples were stored for analyses. The juice yield, total phenolic content and 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging activity were used for screening. Similar experiments were carried out to study the treatment duration of 0, 0.25 h, 0.5 h 0.75 h, 1 h, 2 h and 3 h with the optimal enzyme concentration found in the previous experiment.

2.4. Analytical methods
pH was recorded by using a pH meter. The total soluble solids (TSS) was determined using a refractometer and reported as °Brix. Titratable acidity was measured by titrating with 0.1 N NaOH and displayed as citric acid equivalent. The percentage of juice yield (%) was calculated by Equation (1):

\[
\%\text{Yield} = \frac{M_1 \times C}{M_2 \times (100 - MC)} \times 100\%
\]

where \(M_1\) and \(M_2\) are the weight of cactus cladode juice and mash, respectively, g; \(C\) is total solid content in the obtained juice, % (w/w) and \(MC\) is the moisture content of the fresh mash, %.

The content of soluble poly saccharide substances was expressed in alcohol insoluble solids (AIS) and measured following the reference [16]. In details, 20 g juice was boiled with 300 mL of 80% ethanol for 30 min. The residue obtained from filtration was re-washed with 80% ethanol, and then dried at 100°C for 2 h. AIS would be calculated as percentage by weight.
The Folin-Ciocalteu colorimetric method was used to measure the total phenolic content [17]. 4 mL of the diluted Folin Ciocalteu’s phenol reagent was added into a test tube contains 0.2 mL sample solution. 6 mL of 5% Na₂CO₃ was also added after 5 minutes. Then, the solution should be mixed well using a vortex device and allowed to stabilize at room temperature and dark ambient condition for 60 minutes. A spectrophotometer was used to record the absorbance at 725 nm. Gallic acid was used as control and total phenolic contents was displayed in µg of gallic acid equivalents (GAE) per mL cladode juice.

Total flavonoid content was measured by using the colorimetric method. In specific, a mixture of 2 mL sample and 300 µL of 5% NaNO₂ was mixed well and allowed to react at room temperature in 5 minutes. Next, 600 µL of 10% AlCl₃, 2 mL 1 M NaOH and 1.1 mL distilled water were added in sequence. The mixture should be mixed well by a vortex device and the absorbance was measured by a spectrophotometer at a wavelength of 510 nm. To set a standard, catechin was used. Total flavonoid content was expressed by catechin equivalents (CE) [18].

The antioxidant capacity of juice was examined through DPPH free radical scavenging activity. The volume of 0.2 ml sample solution was mixed with 2.8 mL of a 60 µM DPPH methanol solution. The mixture was kept in dark room at room temperature for 30 minutes. After, the absorbance value was recorded by a spectrophotometer at 515 nm.

Viscosity was carried out by using a Brookfield Viscometer DV – E with the spindle 61 (LV-1) at 25°C [12]. The data of torque expressed as percentage (%), viscosity of solution (Pa.s) were displayed in the screen of the device. For maximum accuracy, the values should be read at 10% to 100% torque. Then, the Newtonian model below based on the method of Yildiz et al. [19] was used to illustrate the rheological study:

\[ \tau = \mu \gamma \]  

(2)

where \( \mu \) is the viscosity of juice (Pa.s), \( \tau \) is the shear stress (Pa), and \( \gamma \) is the shear rate (s⁻¹).

Furthermore, to evaluate the rheological behavior, the Newtonian model and power law model (Ostwaldde-Waale model) were applied [20]:

\[ \tau = K \gamma^n \]  

(3)

where \( K \) is consistency coefficient (Pa.sⁿ), and \( n \) is flow behavior index (dimensionless).

2.5. Statistical analysis

All the experiments were done in triplicate. The statistical analyses were carried out by the SPSS (Statistical Package for Social Sciences) version 22.0 with 95% confident interval. The difference among samples were examined by one-way ANOVA and post-hoc’s multiple tests. All data were reported as the means ± standard deviations.

3. Results and discussion

3.1. Impact of enzyme concentration on the juice extraction process

Figure 1 illustrates the percentage of yield of cactus juice treated with Pectinex Ultra SP-L, Viscozyme and their combination at difference enzyme concentrations. The chart shows that the percentage of yield obtained from treated samples is from 61.62% to 76.02%, while that of untreated sample is 53.23%. It can
be concluded that the application of the enzymes Pectinex Ultra SP-L and Viscozyme helps to enhance the juice yield significantly. Pectinases and carbohydrases from Pectinex and Viscozyme were reported to degrade pectin and cellulose in cell walls. As a result, the release of cell contents increases the yield of juice. These results are consistent with the studies by [21] and [12]. Essa and Salama found that the prickly pear juice yield was improved after treated with pectinases and cellulases. In general, the concentration of 0.2% shows the highest yield. However, there are no significant differences between 0.15% and 0.2% enzyme – treated samples. Therefore, 0.15% (w/w) was considered as the optimal concentration used for improvement of cactus juice yield. Among three studied enzymes, the mixture of Pectinex Ultra SP-L and Viscozyme showed a higher positive effect than its individual enzymes, which suggests that high diversity of enzymes could be more efficient in treating cladode mash to increase juice yield.

Beside juice yield, total phenolic content and DPPH scavenging activity of untreated and treated samples were also investigated and the results are shown in Figures 2 and 3. Figure 2 shows the total phenolic contents in treated cactus juices are significantly higher than that of the control, which are from nearly 49 µg GAE/mL to 69 µg GAE/mL in comparison with 47 µg GAE/mL of the control. Overall, the phenolic content tends to rise when the enzyme dosage increases, where the highest value is obtained for the sample treated with 0.15% Pectinex Ultra SP-L. These results indicate that enzyme treatment could increase the phenolic extraction, which agrees with recent results obtained in treatment of black currant juice [22], where addition of enzyme helped in releasing possible cell wall sited phenolics. Figure 2 also illustrates that every enzyme has a different concentration for optimal extraction of phenolic compounds. Pectinex Ultra SP-L, for example, created the highest phenolic content at 0.15% while a lower value was obtained at 0.2%. This can be explained by the fact that at 0.2% the enzyme-catalyzed degradation of
high-molecular-weight substances in the plant cell wall matrix released more water and other soluble solids rather than phenolics that made the yield of juice increase but lead to the decrease of total phenolic content. Regarding to Viscozyme, there is a slight decrease in phenolic content of the samples treated with 0.1% and 0.15% enzyme concentrations as compared with the value at 0.05% before it raises up and reaches the peak of 60.64 µg GAE/mL at 0.2%. The plant cell walls are very complicated, the location of phenol compounds and their bonding which influence their extraction, are basically unknown [23]. In addition, the concentration or content of phenolics in the treated juice also depends on the extraction of intracellular water. These factors explain the obtained phenomenon.

**Figure 2.** Total phenolic content of cactus juices treated with different enzyme concentrations. Identical letters in the same bars indicate that the data are not significantly different (Tukey test, p > 0.05). The control sample is the one without enzymatic treatment.

Figure 3 indicates that the antioxidant activity of the control sample is 277 µg AAE/mL. The enzymatic treatment could significantly enhance the antioxidant activity (p < 0.05), where the values for the juices treated with Pectinex, Viscozyme and their combination at their optimal concentration of 0.15% are 1.64, 1.67 and 1.73-fold higher than that of the untreated sample. Then, there are noticeable declines in DPPH scavenging activity at the enzyme concentration of 0.2%, which can be explained by the following reason. Commercial enzyme preparations usually include residual contents of various enzymes (such as rutinase, rhamnosidase and laccase) which can modify and convert antioxidants into inactive compounds [24, 25]. Increasing the enzyme concentration may promote the activity of these enzymes leading to lower overall antioxidant capacity of the treated juices. Meanwhile, it is worth noting that the change tendency of DPPH scavenging activity is not necessary to follow that of total phenolic content, e.g. for the samples treated with Viscozyme. This is due to the fact that besides phenolic compounds, other components in cactus juice such as vitamin C, carotenoids and chlorophyll [3] or certain poly/oligosaccharides [26, 27] also contribute to the obtained activity.
Based on the data obtained for juice yield, total phenolic content and DPPH scavenging activity, it can be concluded that the enzyme concentration of 0.15% is considered as the most effective which would be used to investigate the effect of incubation duration in the following section.

### 3.2. Impact of incubation duration on the juice extraction

Figure 4 depicts the juice yield of three enzyme types over three hours of incubation. Overall, the application of enzymatic treatment significantly increases the juice yield, resulting in 27.3-47.1% increment as compared with the control. Although the juice yield could raise up until 2 hours or 3 hours of incubation depending on the enzyme types, there are no significant changes from 0.75 h to 3 h. The data indicates that prolonging the treatment duration could improve juice yield but this occurred only within the first hour of reaction, which agrees with the results of previous studies [28] [29]. The increased juice yield over incubation time is attributed to a greater extent of breaking down the cell walls to release soluble compounds. Among different types of enzyme, the mixture of Pectinex and Viscozyme provides higher juice yield than its individual enzymes with approximately 8% increment.

The effects of incubation on the extraction of phenolic compounds and DPPH scavenging activity were also investigated. Figure 5 illustrates that the level of phenolic content increases significantly when prolonging the treatment time. There are different optimal durations for three systems of enzymes to achieve the highest total phenolic content. Pectinex Ultra SP-L and its mixture display the highest effects at 0.75 h while Viscozyme reaches its peak of total phenolic content at 2 h. After the peak is reached, the total phenolic content tends to keep constant or decrease. The decrease in total phenolic content at extended incubation duration was also reported for other juices such as asparagus [28] and mulberry [30]. That is due to the side effects of trace enzymes in commercial enzymes as discussed above. Among three
enzyme systems, Pectinex Ultra SP-L generated the highest phenolic content of 69.59 µg GAE/mL, followed by Viscozyme with the value of 62.73 µg GAE/mL while their mixture exhibited the lowest value of 59.49 µg GAE/mL.

Figure 4. The percentage of yield of cactus juices treated with different incubation durations. Identical letters in the same bars indicate that the data are not significantly different (Tukey test, p > 0.05). The control sample is the one without enzymatic treatment.

Figure 6 compares the DPPH radical scavenging activity expressed in µg L-ascorbic acid equivalent (AAE)/mL of the cactus juices after treated with difference enzymes from 15 minutes to 3 hours. The antioxidant activities from treated juices have tendency to increase significantly as compared with the control juice. For the samples treated with Pectinex Ultra SP-L, the activity increases slightly and reaches a peak at the 2nd hour with the value of 464.32 µg AAE/mL, but there are no significant differences between 0.75 h and 2 h. When the samples were treated with Viscozyme, the highest DPPH scavenging activity of 475.27 µg AAE/mL was obtained at 3 h. However, the changes of the content from 0.75 h to 3 h are not different significantly. The antioxidant activities of the samples treated with the mixed enzymes also has a similar trend.
Figure 5. Total phenolic content of cactus juices treated with different incubation durations. Identical letters in the same bars indicate that the data are not significantly different (Tukey test, p > 0.05). The control sample is the one without enzymatic treatment.

Based on the data obtained for juice yield, total phenolic content and DPPH scavenging activity, it can be concluded that the incubation duration of 0.75 h is suitable for these enzymatic treatments. Although longer duration could provide further positive effect in certain values, the differences are not significant. Therefore, the combination of 0.15% enzyme concentration and 0.75 h incubation time would be used to produce cladode juices for the investigation on their chemical composition, antioxidant properties, viscosity and rheological behavior in the following sections.
Figure 6. DPPH scavenging activity of cactus juices treated with different incubation durations. Identical letters in the same bars indicate that the data are not significantly different (Tukey test, p > 0.05). The control sample is the one without enzymatic treatment.

3.3. Chemical composition of cactus juices with and without enzymatic treatment

Chemical composition of cactus was examined through pH value, titratable acidity and total soluble polysaccharide expressed in alcohol insoluble solids (AIS). Table 1 shows that there is slight drop in pH and increase in titratable acidity of juices after treated with enzymes. The differences, however, are small. Overall the pH of cactus juice is in the range of 3.98-4.01 and the titratable acidity is in the range of 1.26-1.47 g citric acid/L. Interestingly, the enzymatically treated juices have higher soluble polysaccharide content than the untreated juice. In general, pectinases and cellulases, the main enzymes in Pectinex and Viscozyme, are used in juice processing to break down cell walls for the ease of soluble solid release and to reduce juice viscosity by hydrolyzing soluble polysaccharides in juice. As a result, the AIS content increased as observed in Table 1. Meanwhile, there are no significant differences in AIS content among the juices treated with studied different enzyme systems.
Table 1. Chemical composition of cactus juices with and without enzymatic treatment.

|                        | Control       | Pectinex Ultra SP-L | Viscozyme     | Pectinex Ultra SP-L and Viscozyme |
|------------------------|---------------|----------------------|---------------|-----------------------------------|
| pH                     | 4.07 ± 0.01a  | 4.01 ± 0.01b         | 4.01 ± 0.01b  | 3.98 ± 0.01c                      |
| %AIS (dry basis)       | 7.19 ± 1.13b  | 11.18 ± 1.01a        | 11.98 ± 1.13a | 11.18 ± 0.92a                     |
| TA (g citric acid/L)   | 1.26 ± 0.02c  | 1.43 ± 0.04a         | 1.37 ± 0.02b  | 1.47 ± 0.04a                      |

Note: Identical letters in the same bars indicate that the data are not significantly different (Tukey test, p > 0.05). The control sample is the one without enzymatic treatment.

3.4. Antioxidant properties of cactus juices with and without enzymatic treatment

Table 2 summarizes the total flavonoid content (TFC) in µg catechin equivalent (CE)/mL, total phenolic content (TPC) in µg gallic acid equivalent (GAE)/mL and DPPH scavenging activity in µg L-ascorbic acid equivalent (AAE)/mL of the juices with and without enzymatic treatment. The results indicate that all three studied enzyme systems significantly increase antioxidant contents and capacity of the cactus juice, where the increments are 30.0-60.5%, 19.6-48.1% and 60.1-61.9%, respectively for TFC, TPC and DPPH scavenging activity. Among studied enzymes, Pectinex exhibits better efficiency in extraction of flavonoids and phenolics but no significant difference in antioxidant capacity in the term of DPPH scavenging was found.

Table 2. Antioxidant properties of cactus juices with and without enzymatic treatment.

|                        | Control          | Pectinex Ultra SP-L | Viscozyme    | Pectinex Ultra SP-L and Viscozyme |
|------------------------|------------------|---------------------|--------------|-----------------------------------|
| Total flavonoid content (µg CE/mL) | 23.3 ± 0.3d      | 37.4 ± 0.7a         | 30.3 ± 0.6b  | 33.8 ± 0.2c                       |
| Total phenolic content (µg GAE/mL)  | 47.0 ± 0.1d      | 69.6 ± 1.8a         | 56.2 ± 0.3c  | 58.3 ± 0.1b                       |
| DPPH scavenging activity (µg AAE/mL) | 276.9 ± 4.3c     | 445.9 ± 4.5a        | 448.2 ± 0.5a | 443.4 ± 9.1ab                     |

Note: Identical letters in the same bars indicate that the data are not significantly different (Tukey test, p > 0.05). The control sample is the one without enzymatic treatment.

3.5. Impact of enzyme treatment on viscosity and rheological behavior of cactus juices

Besides chemical composition and antioxidant properties, viscosity and rheological behavior are also important in juice because they determine the pumpable properties as well as heat and mass transfer during juice processing. Table 3 summarizes the viscosity as well as the flow behavior index and consistency coefficient extracted from the Ostwald-de Waele model for rheological behavior of cactus juices with and without enzymatic treatment. Interestingly, although enzymatically treated juices have higher content of soluble polysaccharides as previously shown in Table 1, Table 3 indicates that there are no significant differences in viscosity among all treated and untreated juices. This is due to the fact that viscosity depends not only on content of high-molecular-weight molecules but also on their size and shape, chain entanglement, molecular mobility and intermolecular force, which remain unknown in this study. In addition, Table 3 displays that the flow behavior indexes (n) and consistency coefficient (K) of all samples are in the range of 1.78 to 2.2 and 0.00021 to 0.00075 Pa.s

Note: Identical letters in the same bars indicate that the data are not significantly different (Tukey test, p > 0.05). The control sample is the one without enzymatic treatment.
Table 3. Rheological behavior of cactus juices with and without enzymatic treatment.

|                      | Control | Pectinex Ultra SP-L | Viscozyme | Pectinex Ultra SP-L and Viscozyme |
|----------------------|---------|---------------------|-----------|-----------------------------------|
| Viscosity (mPa.s)    | 11.04   | 11.82               | 10.92     | 10.86                             |
| Flow behavior index (n) | 1.78   | 2.12                | 2.16      | 2.20                              |
| Consistency coefficient (K) | 0.00075 | 0.00029               | 0.00023 | 0.00021                          |

Note: The control sample is the one without enzymatic treatment.

4. Conclusion
In conclusion, the chemical composition and antioxidant properties of the cactus juice were evaluated in this project. The effects of Pectinex Ultra SP-L, Viscozyme and their combination with different enzyme concentrations and incubation durations were also in-depth investigated. The results revealed that the enzymatic treatment has affected significantly on the improvement of cactus juice yield, total phenolic content as well as DPPH scavenging activity. In specific, the concentration of 0.15% was demonstrated to obtain the optimum juice yield, higher total phenolic content and DPPH radical scavenging activity compared to other concentrations. The results also showed that the quality of cactus juice in terms of juice yield and antioxidant properties was increased when prolonging the incubation duration, especially in 0.75 h. Among three different treatments, the mixture of Pectinex Ultra SP-L and Viscozyme at their weight ratio 1:1 released higher juice yield and DPPH scavenging activity than individual Pectinex Ultra SP-L and Viscozyme at their optimal experimental conditions. However, the highest total phenolic content was achieved mostly when treating with Pectinex Ultra SP-L. The data of the present study indicated that cactus juice exhibited shear–thickening behavior at room temperature.

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