Osmotic dehydration and pulsed vacuum osmotic dehydration for
died pineapple production

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ABSTRACT: Osmotic dehydration (OD) has been widely used as a pretreatment of fruits prior to drying. Pulsed Vacuum Osmotic Dehydration (PVOD) is recently certificated for development of new dehydrated fruits. The aim of this work was to evaluate the effect of OD and PVOD on bioactive compounds or ascorbic acid (AA) enrichment of pineapple dried-product. The OD and PVOD process using 2 types of 45°Brix solution (25% kiwifruit juice, 2.5% AA) were conducted. The PVOD provided the highest content and stability of phenolics during storage. The AA infusion was efficient after drying but less advantage during storage. Preservation of AA content required an air and light-tight packaging. OD and PVOD could improve color quality of the dried pineapple products which reduced color change and promoted yellow color. The treated pineapples showed more brittle texture. The sensory acceptability of dried pineapple was highly improved by soaking in kiwifruit juice. These results will provide a good choice to develop functional foods by mixing of physiological active compounds with traditional foods.

Keywords: Antioxidant, Ascorbic acid, Storage, Vacuum, Value-added

Introduction

Dehydration of fruits and vegetables is a process commonly used to preserve the food product. However, collapse of the structure, discoloration and beneficial compound loss are frequent quality problem. Nowadays, consumer requirement is more product quality, providing health benefit. Therefore, functional food development has been increased rapidly. Functional food is defined as any food or food ingredient that provides a health benefit beyond the traditional nutrients it contains (Mazza, 1998). Pineapples, important source of dietary fiber, mineral vitamin and antioxidants. The most abundant antioxidants in pineapples are vitamin C (ascorbic acid, AA), polyphenolics and carotenoids. Most fruits and vegetables are generally dried convectively with 50-80°C drying temperature. The impact of hot air drying on degradation of certain components in fruits has been widely reviewed (Singla et al., 2009, 2011; Chottanom et al., 2012). Because of heat labile property of AA, determination of AA remaining may be a pin point for nutrient quality of dried fruits. The combination of osmotic dehydration (OD) and hot air drying is still widely used process because it can provide required qualities of the dried fruits and vegetables. Efforts have been made to improve traditional drying methods and to design new techniques considering sensorial and functional properties for value-added products. The drying using an advantage technique such as vacuum drying, freeze drying and microwave drying is still not widely used for commercial purpose due to both technique and cost factor. OD, a phenom-

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phenomenon of removal water from lower concentration of solute to higher concentration through semi-permeable membrane of plant material. It has been widely used as a viable process for the partial removal of water from foods by immersion of food pieces in osmotic solutions (sucrose, glucose, corn syrup, maltose, sorbitol, etc.). The water from the food flows towards the solution and, in an inverse sense, the solids from the solution to the product. Therefore, the lower water activity of fruits and vegetables is achieved without phase change under mild temperature. OD is preferred over other methods in food dehydration due to the protective effect offered by the surrounding osmotic solution. Improving the quality of preserved food products, including texture, color, flavor, nutritional constituents, is some of the advantages reported for osmotic dehydration (Torreggiani and Bertolo, 2002). However, when the process is carried out over a long period of soaking time the osmotic solution may not limit the degradation of certain compounds. This is especially true for substances like AA that are easily soluble in water and degrade upon exposure to air. To reduce the osmotic dehydration time, vacuum impregnation (VI) has been used. The vacuum, which results in exchanging the internal gas or liquid occluded in open pores for an external liquid phase, has been used to develop new partially dehydrated products. Combination of VI and OD has been known “pulsed vacuum osmotic dehydration (PVOD)”. PVOD refers to the maintaining of food in osmotic solution for long time after a short period under vacuum. The applied pressure results in a substantial decrease in the volume of gas remaining in the pores. Thus, an increase in the flow of the external liquid into the pores becomes feasible. The advantages of PVOD are its use for formulating porous foods, promoting effective diffusion in fruit’s liquid phase, and increasing mass and volume in a long-term process. Because of its useful way of introducing liquids into the porous structure of some foods (Moraga et al., 2009; Moreno et al., 2012; Betoret et al., 2012), vacuum impregnation over the past few years has been used to develop a new technology producing functional food products. Interestingly, vacuum impregnation has been reported as a procedure that can provide an original fresh structure incorporated with active compounds like calcium, iron salts (Zhao and Xie, 2004) and flavonoids. Concerning loss of soluble substances in food, the simultaneous countercurrent flows of internal and external mass induced by vacuum impregnation can’t be ignored and the phenomenon explanation is still inadequate. So, finding the appropriate method for drying pineapple in order to meet a value-added dried fruit or a functional dried fruit is challenging work. The aim of this work was to evaluate the effect of OD and PVOD on bioactive compounds or ascorbic acid enrichment of pineapple dried-product. The efficient process for functional foods by mixing of physiological active compounds with traditional foods was developed.

Material and Method

Pineapple preparation

The study was conducted with pineapple pieces (2 mm thickness) at commercial maturity. The pineapple pieces were soaked in 0.5% \( \text{CaCl}_2 \) and 50 ppm of \( \text{Na}_2\text{SO}_3 \) solution for 30 min. and
then drained before subjecting to further soaking method.

**OD and PVOD procedure**

Soaking method of OD and PVOD was applied with the 2 types of 45°Brix solution including 25% kiwifruit juice+sucrose and 2.5% AA+sucrose. The total soluble solid of 45°Brix was adjusted by using sucrose. The OD process was conducted by soaking pineapple pieces in the solutions for 6 at atmospheric pressure. In the PVOD process, the pineapple samples were vacuum impregnated in the solutions with 1:4 ratio of sample to solution in a closed cylindrical chamber, and then the air in the chamber was immediately pulled out to reach the vacuum pressure (residual pressure 50 mbar) by using a vacuum diaphragm pump. The vacuum was maintained for 10 min and gently released. After the vacuum impregnation step, the samples were then restored in atmospheric pressure for 6 h. The samples were then drained and kept at 4°C before analysis.

**Air drying**

All soaked pineapple samples were dried in a tray drier at 80°C until their aw value were 0.35-0.45 to obtain crispiness texture of the products. Drying air temperature was monitored by using a thermocouple connected to a data logger with an accuracy of ±1°C. The obtained dried-products were storaged for 2 month at ambient temperature in polyethylene (HDPE) and aluminum foil laminating pouches. The unsoaked dried pineapple was served as a control sample.

**Product characteristics**

Color measurement was performed by using a Minolta color meter (CR-300, Japan). The coordinates of the color CIE-L* a* b* of the sample surface were obtained by reflection. The L*, a* and b* represent lightness, redness, and yellowness values, respectively. The total color change (ΔE*) was calculated as follows:

\[
\Delta E^* = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}
\]

where ΔL, Δa, Δb are the changes in each individual color parameter between initial and storaged samples. Texture measurement was performed by using a TA.XT2i texture analyzer (Stable Micro System, UK) to determine puncture force passed through the samples. The cylinder probe of 2 mm diameter was used. The test speed was 1 mm/s. The distance between two brackets was 2.7 cm. Ten samples were used in each treatment. The force values of the highest peak of penetration were recorded as hardness values. Each result was an average value from three replicate measurements.

The Folin-Ciocalteu method slightly modified from Bae and Suh (2007) was used to determine phenolic content. The absorbance value was measured by using spectrophotometer (Milton Roy Spectronic 1201, USA) at 750 nm and the result was expressed as mg gallic acid equivalents/g sample. Ascorbic acid content (AA, mg/100g tomatoes) of the pineapple products was determined by titration with 2,6-dichlorophenolindophenol (dye solution) in accordance with the method used by Askar and Treptow (1993) with slight modifications.

Sensory acceptence of dried pineapple products was evaluated by using 9-point Hedonic scale (dislike extremely-like extremely). The
evaluated parameters, appearance, color, flavor, texture and overall acceptability were obtained from 30 panelists.

**Statistical Analysis**

Triplicate experiments were performed using factorial experiment in completely randomized design and the mean values plus standard deviation were calculated. All of the data were subjected to analysis of variance (ANOVA). Significant difference between experimental means was determined by using the Duncan’s multiple range tests (p<0.05).

**Results**

Table 1 shows the amount of ascorbic acid (AA) and phenolic compounds of dried pineapples. Before storage, different values of certain substances were observed which caused by various soaking treatments. In the case of initially dried products, stability of AA was significantly improved by all soaking treatments, with the exception of the PVOD, AA treatment. Even the samples were soaked in AA solution; the AA content was similar to the control sample. The AA content in soaked samples up to 1.3 to 1.7-fold was greater than those in a control sample. However, PVOD method did not promote AA infusion when compared with OD method. The simultaneous countercurrent flows of internal and external mass and matrix change induced by vacuum impregnation should be taken into account. This is especially true for substances like AA that are easily soluble in water and degrade upon exposure to air. Therefore, large amount of water loss might cause leaching out of AA. In previous work, water loss higher than 10 g/100 g tomatoes caused a significant loss of ascorbic acid (Chottanom et al., 2016). Interestingly, PVOD method was useful when the kiwifruit juice was used instead of AA solution. Likewise, a stability of phenolic compounds was also significantly improved in the sample soaked in kiwifruit juice under vacuum pressure. And the phenolic content in a PVOD, kiwifruit juice sample up to 3.7-fold was greater than those in a control sample.

**Table 1** The ascorbic acid and phenolic contents (mg/g sample) of dried pineapple products in PE pouches.

<table>
<thead>
<tr>
<th>Treatments*</th>
<th>Ascorbic acid</th>
<th>Phenolics</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
<td>Storaged</td>
<td>% Loss</td>
<td>Initial</td>
</tr>
<tr>
<td>Control</td>
<td>42.85 ± 2.52a</td>
<td>24.99 ± 2.52b</td>
<td>41.68</td>
<td>11.86 ± 0.20b</td>
</tr>
<tr>
<td>OD, Kiwifruit juice</td>
<td>65.17 ± 1.26bc</td>
<td>29.46 ± 1.25c</td>
<td>54.80</td>
<td>17.03 ± 0.05c</td>
</tr>
<tr>
<td>PVOD, Kiwifruit juice</td>
<td>61.60 ± 1.26b</td>
<td>25.89 ± 1.26b</td>
<td>57.97</td>
<td>44.35 ± 4.40a</td>
</tr>
<tr>
<td>OD, AA</td>
<td>73.21 ± 2.52c</td>
<td>19.63 ± 2.52a</td>
<td>73.19</td>
<td>4.43 ± 0.03a</td>
</tr>
<tr>
<td>PVOD, AA</td>
<td>55.35 ± 2.52a</td>
<td>16.33 ± 2.52a</td>
<td>70.50</td>
<td>9.01 ± 0.03b</td>
</tr>
</tbody>
</table>

*Total soluble solid of all soaking solutions was adjusted to 45oBrix by using sucrose.

After storage for 2 months, AA content could not be preserved by both OD and VPOD infusion, showing 54-73% loss in the stored products. In addition, AA retention was not improved by PVOD, kiwifruit juice treatment for stored products when compared with control one. Previous studies have shown that AA and other active substances can be added to an osmotic solution.
to preserve product stability. However, this result exhibited a rapid loss of AA in the dried fruit that kept in a moisture barrier pouch like PE film. In the case of phenolic content, the PVOD was an excellent process in antioxidant fortification in dried pineapple. Mandarin juice containing high flavonoid content was used as an osmotic solution to produce a functional apple snack Chenlo (2006). The difference phenomenon between phenolics and AA infusion could not be explained clearly. The factors affecting their diffusion include molecular size, mobility, bonding, concentration and cell plasmolysis etc. In addition the stability under oxygen condition is taken into account as well. Generally, the large amount of AA loss of in dried fruits has been found after hot air drying and storage exposing to oxygen, heat and light. The loss of certain substances could be decreased by using packaging with air and light-tight. Figure 1 shows the stability of AA and phenolic compounds in different packaging. A laminating pouch provided more stability of AA and phenolic content than a PE pouch. The AA content of soaked samples in a laminating pouch up to 1.3 to 2-fold was greater than those in a PE pouch, (with the exception of the control sample) and phenolics was also preserved up to 1.2-2 fold.

Figure 1 Comparison of the ascorbic acid or phenolic contents (mg/ g sample) of dried pineapple products in PE and laminating pouches after storage for 2 months (Different letters represent significantly different (p<0.05) to evaluate the effect of packaging type in each treatment).

Table 2 shows effect of soaking methods on texture of dried pineapple products. All soaking treatments bring about less hardness values, compared with a control one. The brittle texture of all pretreated products still remained during storage, while a control sample was harder. Around 2-fold hardness values increased after storage. Shrinkage of dried fruits generally found on the products dried without using a good pre-treatment. Concerning, volume retention of the fruit product could be found by using the vacuum when it let to high solid gain in the product (Choi et al., 2006; Patras, 2009). However, detriment of cells may occur under vacuum pressure for soft food matrix. In addition, the time needed to go back to atmospheric pressure, a confidential step, is also regarded as a key factor relating to structure change.
Table 2 | Hardness values (N) of dried pineapple products.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Initial</th>
<th>Stored</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>9.73±6.23b</td>
<td>18.12±2.01b</td>
</tr>
<tr>
<td>OD, Kiwifruit juice</td>
<td>8.13±2.46ab</td>
<td>7.81±2.56a</td>
</tr>
<tr>
<td>PVOD, Kiwifruit juice</td>
<td>8.75±4.67b</td>
<td>9.71±5.18a</td>
</tr>
<tr>
<td>OD, AA</td>
<td>4.65±3.04ab</td>
<td>7.11±3.20a</td>
</tr>
<tr>
<td>PVOD, AA</td>
<td>3.21±3.20a</td>
<td>10.88±3.67a</td>
</tr>
</tbody>
</table>

Table 3 | Color parameters of dried pineapple products.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>L'</th>
<th>a'</th>
<th>b'</th>
<th>(ΔE*)'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>70.65±0.25d</td>
<td>14.28±0.24a</td>
<td>24.78±1.05a</td>
<td>23.85±0.54c</td>
</tr>
<tr>
<td>OD, Kiwifruit juice</td>
<td>62.63±0.11c</td>
<td>4.33±0.17d</td>
<td>43.64±0.62a</td>
<td>13.42±0.62b</td>
</tr>
<tr>
<td>PVOD, Kiwifruit juice</td>
<td>62.20±0.90c</td>
<td>4.16±0.48a</td>
<td>38.95±0.22d</td>
<td>6.20±0.74a</td>
</tr>
<tr>
<td>OD, AA</td>
<td>57.24±0.12a</td>
<td>3.44±0.20a</td>
<td>36.88±1.28c</td>
<td>13.74±4.38b</td>
</tr>
<tr>
<td>PVOD, AA</td>
<td>58.75±0.10b</td>
<td>2.70±1.85b</td>
<td>33.56±1.41b</td>
<td>13.07±3.89b</td>
</tr>
</tbody>
</table>

*ΔE* is the total color difference between the storage products and the initial products, calculated by using equation 1.

Decreasing of lightness could be explained by the increasing of solid fraction (solid gain) by OD and PVOD, which increased the light refraction. On the other hand, b' values of the pretreated samples were higher than those of the control one, indicating the effect of osmotic solutions on color improvement. Moreover, a’ values was quite low in all pretreated samples. The browning reaction (Maillard) was clearly inhibited by the solutions. After 2 months of storage, the effect of pretreatments on color stability was clearly exhibited on all soaked samples. Amount soaked sample, the lowest ΔE' values was found in the sample soaked in kiwifruit juice using PVOD.

Table 4 | Sensory scores of dried pineapple products.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Appearance</th>
<th>Color</th>
<th>Flavor</th>
<th>Texture</th>
<th>Over all acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>6.63±0.71b</td>
<td>5.96±0.31</td>
<td>3.00±0.45b</td>
<td>5.06±0.44b</td>
<td>5.0±0.31b</td>
</tr>
<tr>
<td>OD, Kiwifruit juice</td>
<td>7.93±0.36c</td>
<td>7.86±0.43a</td>
<td>7.70±0.59a</td>
<td>7.83±0.53a</td>
<td>8.0±0.31a</td>
</tr>
<tr>
<td>PVOD, Kiwifruit juice</td>
<td>8.93±0.25d</td>
<td>8.10±0.48b</td>
<td>8.86±0.50b</td>
<td>8.03±0.31a</td>
<td>8.9±0.40b</td>
</tr>
<tr>
<td>OD, AA</td>
<td>7.80±0.48c</td>
<td>3.93±0.36b</td>
<td>4.86±0.43c</td>
<td>5.76±0.43c</td>
<td>5.9±0.40c</td>
</tr>
<tr>
<td>PVOD, AA</td>
<td>6.86±0.68b</td>
<td>4.86±0.34c</td>
<td>5.76±0.62a</td>
<td>6.66±1.06d</td>
<td>6.6±0.92d</td>
</tr>
</tbody>
</table>
Table 4 shows sensory scores of dried pineapple products. All soaking methods clearly increased dried pineapple quality. The sensory scores were satisfied adequately. The highest overall acceptance scores in the products soaked in kiwifruit juice were approximately 8.0-8.9, indicating like highly-like extremely, contributing from high scores of appearance, color, flavor and texture of the products. While, the overall acceptance scores (like slightly-like moderately) of the products using AA solution (OD, PVOD) were closed to those of the control sample, possibly due to sour taste and low color quality.

Discussion

The result shows increasing of AA by OD and PVOD, with the exception PVOD using AA. Silva, et al. (2013) found that AA gained in pineapple tissue affected by AA concentration in the solution but it might lose along the water loss. In addition, they noted that diffusion of water and sugar increased significantly in the presence of AA in the solution. Chottanom et al. (2016) noted that the effects of the vacuum process integrated with osmotic dehydration could not be observed when the water loss was higher than 10 g/100 g tomatoes. The significant loss of AA was then exhibited. In our work, pineapple pieces with low thickness were used. Possibly, the combination effect of acidic fortification (2.5% AA) in the tissue and vacuum pressure damaged the cell/structure of the sample. This damage did not show in the OD method. Therefore, the use of vacuum should be optimized, focusing accordance of additive concentration, water loss, solid gain, cell collapse / volume reduction and reaching out of certain compounds. AA is known as a labile active substance that loses its activity easily due to a number of factors like temperature, oxygen, light, metal irons, enzyme and pH (Uddin, Hawlader, and Zhou, 2001). In addition, it is easily soluble in water. The large amounts of AA leached easily out into the osmotic medium along a large amount of water flux because of the effect of concentration difference. Stability of AA might depend upon its concentration in food before subjecting to drying. AA from an osmotic solution containing 10% AA was sufficiently incorporated in a potato tuber during the vacuum impregnation process carried out with long term restoration (Hironaka et al., 2011). Moreover, during the drying process, AA degradation was clearly found to be moisture and temperature dependent. In drying process, the loss of AA is affected specially by high temperatures. According to Zanoni et al. (1999), degradation rate of AA in tomatoes, at 80 and 110°C, was dependent of temperature and moisture and vitamin C was not detected in samples dried above 100°C (Villota et al., 1980). Generally, color of dried fruit was altered by degradation of pigments and chemical reaction. Carotenoid, a color pigment in pineapple is an oxidativeable substance by exposure to oxygen which is induced by heat. Generally, fruits and vegetables are dried using air temperature ranged from 50°C to 80°C for 1 h to 24 h (Chottanom, 2012). The losses of certain compounds occur not only during the dehydration process but also during storage exposed to oxygen. Therefore, degradation of oxidativeable substances such carotenoids starts up easily during the air drying process and may increases along a storage time. In addition, color change in dried fruits and vegetables normally caused by
Maillard reaction which exhibits a maximum rate at the intermediated $a_w$ of the foods. The Maillard reaction creates brown pigments by rearranging amino acid and certain sugars (reducing sugars) to give the product brown color. Indeed, the Maillard reaction can speed up because of high drying temperature like 80°C, contributed to less $L^*$ and $b^*$ values and more $a^*$ value in a control sample. In the treated sample case, the formation of a periferic layer of sucrose occurred during osmotic dehydration was responsible for oxygen barrier. Moreover available water in food materials is easily held by sucrose molecule. These could provide a protective effect for certain compounds. Mentioning among the treated samples, the low $L^*$ and $b^*$ values were found by PVOD or OD using AA instead of kiwifruit juice. The explanation of this result could be noted that color change related with cell collapse or structure damage of the product. PVOD process using AA resulted in a considerable decreasing of hardness. The structure preservation after OD processing depends upon many processing factors, i.e. osmotic agents, concentration, temperature, pressure, etc. The negative effect of high vacuum pressure on texture has been reported in partially ripe mangoes (Sriwimon and Boonsupthip, 2011).

Conclusion

The soaking treatments provide dried pineapples with high AA and phenolics but could not improve AA stability during storage. The PVOD provide high stability of phenolics. The AA infusion was not sufficiently improved because of rapid degradation by environment factors during storage. However, it might be preserved by using the appropriate packaging. The air and light-tight packaging was more necessary for the functionally dried fruit that fortified with AA compared to phenolics. Regarding color stability of the treated samples compared with a control one, all treatments created in this study could improve the color quality of the dried pineapple products as indicated by the lower total color change and high yellow color. The soaked samples showed more brittle texture. The sensory acceptability of dried pineapple was significantly improved by soaking treatments using kiwifruit juice.

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References


