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Pulsed Vacuum Osmotic Dehydration of Cherry Tomatoes: Impact on Physicochemical Properties and Probiotics Entrapment

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Abstract

Osmotic dehydration (OD) and pulsed vacuum osmotic dehydration (PVOD) were employed to assess the various properties of partially-dehydrated tomatoes. Ascorbic acid and lycopene degradation and color and texture change were determined. The mastership incorporation of probiotics (*Lactobacillus acidophilus* TISTR 1338) into tomatoes was also investigated. OD mediums (20, 40 and 60 °Brix) consisted of a mixture of formulated tomato extract (FTE) and probiotic cell suspension. PVOD promoting mass transfer was clearly observed in a short-time process compared with OD. The physical and chemical properties of the tomatoes changed significantly after the dehydration processes, especially those of ascorbic acid content compared with lycopene. A more than 50 % loss of ascorbic acid was noted, starting at 10 g /100 g tomatoes of water loss. The hardness values significantly increased, while chroma values decreased. The cell entrapment on the tomatoes was in the range of 8 - 9 log CFU/g tomatoes. The highest entrapment of the probiotic bacteria was found in the long-time process (12 h) conducted with 20 °Brix FTE for the PVOD and OD processes, while entrapment was decreased by the short-time process (6 h). Using high solution concentration resulted in lower cell entrapment. However, cell entrapment could be increased by using the vacuum process. These results will provide a platform that encourages the inclusion of probiotics in high quality fresh-cut products and semi-moist products. These products can then be considered as alternative probiotic food choice for consumers.

Keywords: Cherry tomatoes, medium concentration, osmotic dehydration, probiotics, pulsed vacuum osmotic dehydration

Introduction

Cherry tomatoes (*Solanum lycopersicum* var. c*erasiforme*) are a good source of natural antioxidants such as lycopene, ß-carotene, and ascorbic acid. Lycopene, belonging to the carotenoid family, is the major antioxidant in tomatoes. Processing and storage (high temperature, time, light, oxygen exposure) of tomatoes cause degradation of the antioxidants [1,2]. Osmotic dehydration (OD), immersing food samples in osmotic solutions (sucrose, glucose, corn syrup, maltose, sorbitol, etc.), is a viable process for the partial removal of water from cellular foods without a phase change. The water from the food flows towards the solution and, in an inverse sense, the solids from the solution to the product. It has been claimed that the OD technique has the advantage of preserving natural compounds. This is attributable to the low temperature that is applied during the process, as well as the protective effect offered by the surrounding osmotic solution. However, when the process is carried out over a long

period of time, the osmotic solution may not limit the degradation of certain compounds. This is especially true for substances, like ascorbic acid, that are soluble in water and degrade upon exposure to air. To reduce the osmotic dehydration time, vacuum impregnation 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. Pulsed vacuum osmotic dehydration (PVOD) is an application of vacuum pressure assisted osmotic dehydration. The PVOD operation consists of 2 steps. In step number one, a food sample is soaked in an osmotic medium, like sucrose syrup or syrup mixed with some active substances, and then immediately imposed with vacuum pressure (~50 - 100 mbar) for a short time (10 - 30 min) in a closed tank [3-6]. The internal gas expands and is expelled from the open pores. The released gas takes the product pore native liquid with it. In step number two, atmospheric pressure is restored in the tank. 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 driving forces in the vacuum process are pressure gradients and capillary action. Osmotic dehydration (OD) contributes to capillary action, resulting in a significant reduction of water and a loss of natural substances such as minerals, vitamins and acids in the tissue. The PVOD process causes a food structure change that is different from the change caused by OD. This is because of the different pressure drops of fluid in the intercellular pores that were created during step number one, namely, flowing toward the volume generated by water loss [7]. 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 [8-11], 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 being a procedure that can provide an original fresh structure incorporated with active compounds like calcium, iron salts [7,10], and flavonoids [12]. Moreover, vacuum impregnation is often claimed to be a feasible way of incorporating some probiotic microorganisms, with the objective of developing a procedure to produce functional fruit products such as dehydrated fruits [8,13], partially dehydrated fruits [11], and minimally processed fruits [5,6].

Probiotics are live microorganisms, which, when administered in adequate amounts, confer a health benefit on the host [14]. Two widely used strains in probiotic foods are *Lactobacillus* sp. and *Bifidobacteria* sp. [15]. Generally, the limited production of probiotic food products follows 2 major routes. In the first route, probiotics are grown in a fermented food matrix of milk and vegetables, and in non-fermented liquid products. In the second route, the biomass of probiotics is mixed into end products, such as infant formula, milk powders and cereals [16]. Nowadays, fermented milk is mainly available in the marketplace. However, numerous consumers cannot take dairy products because of lactose intolerance and cholesterol content limitations. As such, alternative probiotic food choices like fruits and cereals are currently undergoing studies. Entrapment and survival of probiotic cells in a fruit matrix prior to applying the next processing step is a challenging investigation. Vacuum impregnation is currently used as the technique for pushing osmotic solutions with probiotic cells into fruit tissue.

The literature review above presents numerous practical uses of vacuum impregnation for development of new products. However, simultaneous countercurrent flows of internal and external mass induced by vacuum impregnation cannot be ignored. Even though more external components can easily enter product pores, the same drawback of natural component flow can also occur, because of greater diffusivity promotion, which leads to the modification of the product's chemical and physical characteristics. The modification of osmosed product characteristics is dependent on important factors such as fruit structure and process condition. The negative effect of vacuum pressure on texture has been reported in partially ripe mangoes [6]. However, volume retention of the fruit product could be found by using the vacuum leading to high solid gain in the product [17,18]. Vacuum impregnation can effectively promote the diffusion mechanism in the pores, especially when the process is carried out with a low viscous solution: the higher the fruit porosity, the greater the diffusivity promotion by vacuum impregnation [7]. So, the main processing factors contributing to the vacuum impregnation process are tissue structure (pore and size distribution), relaxation time of the solid matrix (a function of the

mechanical properties of the materials), transport rate of the hydrodynamic mechanism (of significant importance in operations involving vacuum treatment), viscosity of the osmotic solution, and the size and shape of the sample [19,20]. In addition, the time needed to restore atmospheric pressure, a confidential step, is also regarded as a key factor relating to structure change. So, finding the appropriate vacuum impregnation condition to meet and satisfy the characteristics of products is challenging work.

The objective of this investigation was to evaluate the effect of concentrations (diluted-concentrated) of PVOD and OD mediums on ascorbic acid and lycopene degradation, texture and color change, and entrapment of *Lactobacillus acidophilus* TISTR 1338 in partially dehydrated tomatoes.

Materials and methods

Tomato Preparation

Ripe fresh cherry tomatoes (*Solanum lycopersicum* var. cerasiforme) were always purchased from the same supplier in Mahasarakham province, Thailand. Tomatoes, weighing 1,500 g and of the same size and color, were blanched in boiling water for 2 min and then cooled for 30 min in distilled water with citric acid added (1.5 g citric acid/100 ml water). The tomatoes were then peeled and halved.

Culture Preparation

Lyophilized probiotic bacteria, *L. acidophilus* TISTR 1338, from the TISTR Culture Collection Center (Thailand) was grown in MRS broth (Himedia laboratories) at 37 °C for 24 h and then plated on MRS agar to a single culture colony. The culture colony was again grown in MRS broth at 37 °C for 14 h. The obtained *L. acidophilus* TISTR 1338 cells were then washed with a citric-sodium citrate buffer by centrifugation at 7,000 rpm for 15 min three times and then suspended in citric-sodium citrate buffer before filling in formulated tomato extract (FTE), a mixture of tomato extract and sucrose syrup with concentrations of 20, 40 and 60 °Brix. Three different FTE concentrations with 10^{10} CFU/ml *L. acidophilus* TISTR 1338 were employed to achieve the probiotic-enriched tomatoes.

Impregnation procedure

The 2 methods of impregnation were osmotic dehydration (OD) and pulsed vacuum osmotic dehydration (PVOD). The OD treatment was conducted by soaking halved tomatoes in FTE at atmospheric pressure for 6 and 12 h. In the PVOD treatment, halved tomatoes were vacuum impregnated in FTE with a 1:1 ratio of tomato to FTE [33] 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 tomatoes were restored in atmospheric pressure for 6 and 12 h. The tomato samples were then drained and packed in a sterilized container and kept at 4 °C before analysis. The experiment was conducted at room temperature and the soaking medium temperature was in the range of 26 - 27 °C.

Water Loss and Solid Gain Determination

The water loss (WL) and solid gain (SG) were analyzed after the impregnation processes. The WL and SG values expressed in gram per 100 g tomatoes were determined by using Eqs. (1) - (2).

$$WL = \frac{m_o W_o - m_t W_t}{m_o} \cdot 100 \quad (1)$$

$$SG = \frac{m_t S_t - m_o S_o}{m_o} \cdot 100 \quad (2)$$

where m_t and m_o are the mass of tomatoes at time *t* and time zero, respectively. W_o and S_o are the initial values (at time zero) of water content (mass fraction) and solid content (mass fraction) of the tomatoes, respectively. W_t and S_t are the water content (mass fraction) and solid content (mass fraction) values of the tomatoes at time *t*, respectively.

Lycopene Measurement

The lycopene content (mg/100 g tomatoes) of the impregnated tomatoes was spectrophotometrically determined on extracts in petroleum ether in triplicate at 505 nm [21] by using a UV-Visible spectrophotometer (Milton Roy Spectronic 1201, USA). The lycopene content was quantified using the standard curve of 95 % purified lycopene (Sigma Chemical Co., St. Louis, USA), dissolved in petroleum ether.

Ascorbic Acid Measurement

The ascorbic acid content (mg /100 g tomatoes) of the impregnated tomatoes was determined by titration with 2,6-dichlorophenolindophenol (dye solution), in accordance with the method used by Askar and Treptow [22] with slight modifications. An aliquot of the sample was prepared by homogenization of 10 g of tomato with 10 ml of 3 % meta-phosphoric acid. The aliquot was diluted with 10 ml of distilled water and then filleted. The 10 ml filtrate was taken for titration with a dye solution. The calculation of ascorbic acid content was based on the standardization of the dye solution [23].

Texture Measurement

Tomato hardness was measured with a universal testing machine (LLOYD Instruments ^{TM}, UK). For each sample, 4 tomato pieces were compressed at 1 mm/s test-speed with a 3.18 mm diameter cylinder probe setting at 30 % strain into the sample tissue.

Color Measurement

The skin color of the tomato samples was directly measured as reflected color in CIE-$L^*a^*b^*$ using a color meter (Minolta, CR-300). For each sample, 5 pieces were measured at 2 positions and the mean values were recorded. L^*, a^* and b^* represented the lightness, redness, and yellowness values, respectively. The total color difference (ΔE^*) and chroma values were calculated following the equation below.

$$\Delta E^* = \left[\left(L_o^* - L_t^*\right)^2 + \left(a_o^* - a_t^*\right)^2 + \left(b_o^* - b_t^*\right)^2\right]^{1/2} \quad (3)$$

$$Chroma = \left[\left(a^*\right)^2 + \left(b^*\right)^2\right]^{1/2} \quad (4)$$

where L^*, a^* and b^* represent the lightness, redness, and yellowness values of fresh (o) or treated tomatoes (t), respectively.

Enumeration of *L. acidophilus* TISTR 1338 in Tomatoes

At regular FTE and impregnation times, the 10 g tomatoes were blended in a stomacher bag and then serial diluted with 0.1 % peptone water until a suitable dilution was reached. The viable cells were counted by the pour plate technique on MRS agar after being incubated for 48 h at 27 °C. Means of viable count were presented as CFU/g tomatoes.

Statistical Analysis

Triplicate experiments were performed, and the mean values plus standard deviation were calculated. All of the data were subjected to analysis of variance. Significant difference between experimental means was determined by using Duncan's multiple range tests (DMRT).

Results and discussion

The advantage of OD is generally understood as a partial removal of water from food and a gain in solids or certain substances into food, while water soluble substances may be partially lost. Therefore, impregnation in an OD medium mixed with fruit or vegetable extracts is interesting in terms of substance retention. OD treatment that affects the physical and chemical properties of fruits and vegetables is looked upon as having important process conditions, i.e., medium agents, temperature, concentration, and contact time. In this study, the moisture of fresh tomatoes was reduced by around 1 - 34 % when the 20 % - 60 °Brix FTE was used (data is not shown), leading to 11 - 47 g/100 g tomatoes and 0.2 - 31 g/100 g tomatoes of WL and SG, respectively (**Figure 1**). The highest water loss and solid gain values were clearly shown in the treatments conducted with 60 °Brix FTE for 12 h. Moisture reduction, depending upon concentration differences of food and medium, has been concluded [24-26].

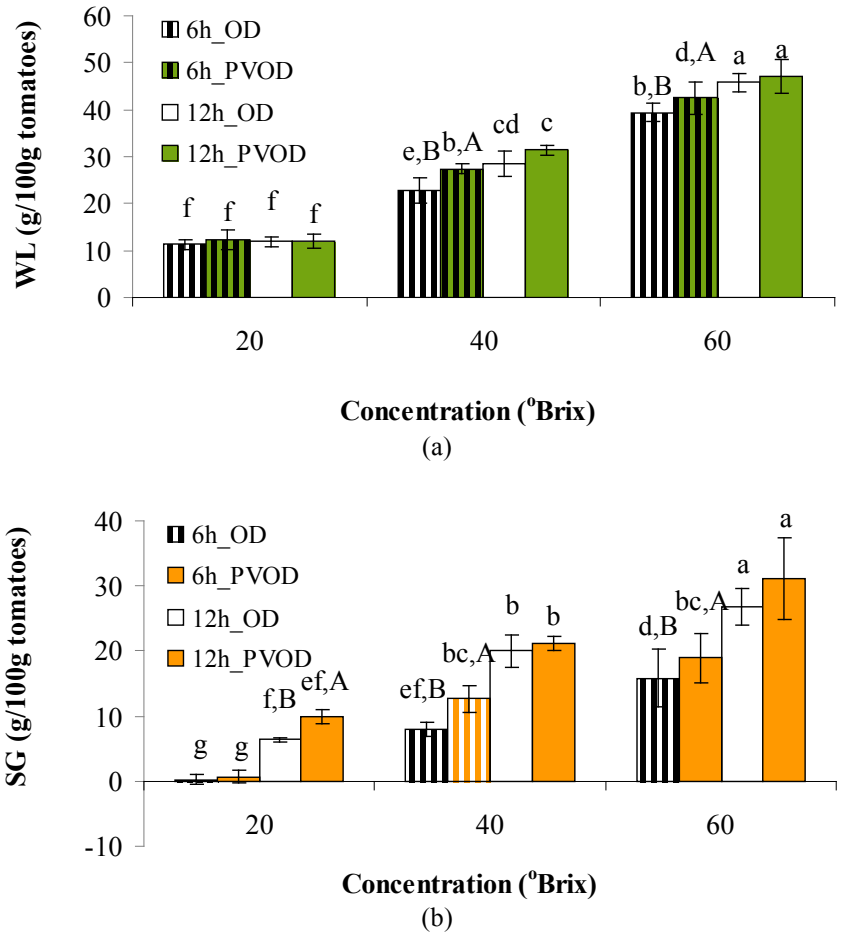

Figure 1 Water loss (a) and solid gain, (b) values of tomatoes after impregnation processes.
[a,b]Different letters show significant differences ($p < 0.05$) by using the DMRT.

Generally, using high medium concentration brings about high water transfer. Concentrated medium, i.e. 60 - 70 % w/w, could decrease to around 30 - 50 % moisture content in fresh fruits and vegetables [10]. Moreover, the effect of vacuum pressure on mass transfer could be observed in the results. Water loss and solid gain increased significantly using PVOD, when compared with OD, particularly in the 40 and 60 °Brix FTE treatments. In the processes using 40 and 60 °Brix FTE, water and solid transfers were promoted when the experiments were conducted using the short-time (6 h) process. The advantage of the vacuum did not show in the long-time (12 h) process, except for the 20 °Brix treatment, possibly due to the equilibrium approach of mass transfer. The increase of mass transfer that resulted from vacuum also depended on food structure and medium concentration. The advantage of the vacuum process was noticeable in porous materials soaked in viscous medium (50 - 70 % w/w) [4,19].

Ascorbic acid 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. In addition, it is easily soluble in water. Osmotic dehydration has been claimed to be a pretreatment that preserves ascorbic acid and other compounds in processed fruits and vegetables [27-31]. On the other hand, numerous investigations have been conducted into the water soluble properties of ascorbic acid, and the findings reveal a substantial reduction in concentration during the osmotic process. The fresh tomatoes used in the presented work contained ascorbic acid and lycopene in amounts of around 18.30 and 16.72 mg/100 g tomato samples, respectively. The results in **Table 1** show the explicit effect of the impregnation process on ascorbic acid loss in more than 50 % of all treatments, while the lycopene substance remained quite stable. Previously, the effect of the vacuum process on ascorbic and lycopene loss (the same solution concentration and restoration time treatments) was analyzed. The effects of the vacuum process integrated with osmotic dehydration could not be observed. In this work, water loss of higher than 10 g/100 g tomatoes caused a significant loss of ascorbic acid. The 2 possible reasons could be explained: Firstly, diluted osmotic medium could not serve as an oxygen barrier for tomato tissue. Secondly, large amounts of ascorbic acid leached out into the osmotic medium along the water flux because of the effect of the concentrated medium, and further degradation was caused by exposure to oxygen over a long period of time. Investigations concerning the loss of some active compounds have been reported. Previous studies have shown that ascorbic acid and other active substances can be added to an osmotic solution to preserve product stability. Mandarin juice containing high flavonoid content was used as an osmotic solution to produce a functional apple snack [13]. Ascorbic acid from an osmotic solution containing 10 % ascorbic acid was sufficiently incorporated in a potato tuber during the vacuum impregnation process carried out with long term restoration [32]. Lycopene is known as an oxidativeable substance by exposure to oxygen which is induced by heat. Normally, lycopene is barely soluble in water compared to ascorbic acid. Therefore, only a small reduction could be found after the impregnation process. Lycopene reduction was in the range of 0.07 to 3.83 %.

The effect of the impregnation process on the hardness values of tomato samples is shown in **Table 2**. The approximate hardness value of the fresh tomatoes used in the presented work was 30.88 g. The significant increase in the hardness of tomatoes found after the impregnation was due to water loss and/or solid gain. The effect of vacuum on texture was also analyzed. Vacuum clearly resulted in an increase of tomato hardness in 40 and 60 °Brix treatments because of water loss and solid gain promoted by vacuum application. Interestingly, vacuum application seems to retain tomato texture, as shown in 20 °Brix, 12 h, PVOD treatment, possibly due to an adequate SG content inside.

Color parameters (L^*, a^*, b^*) of tomatoes were clearly changed by the impregnation process (**Table 3**). There were various lightness values, while redness and yellowness values were significantly decreased. The total color change (ΔE^*) between the untreated (fresh tomatoes) and treated samples was also evaluated. Normally, diluted medium may not protect food from an oxidation reaction. Considering the 20 °Brix, OD, 6 h treatment, high ΔE^* and low chroma values were observed, possibly due to low solid gain. On the other hand, the vacuum preserved the color. However, the advantage of the vacuum, that it could provide sufficient solid gain in tomatoes, was not evident in the 12 h process.

Table 4 shows the number of *L. acidophilus* TISTR 1338 that adhered to the tomatoes after the impregnation process. In this study, probiotic suspension with a concentration of 10 log CFU/ml was

added to the FTE. High probiotic biomass was employed to meet close to 9 log CFU/g tomato entrapment. Scientific evidence suggests that probiotic concentration consumed at high levels, like 9-10 log CFU/day, has health benefits that may be limited by some intestinal illness [33,34]. However, various suggestions on a minimum probiotic concentration consumed for health benefits can also be found. Previous studies showed concentrations higher than 6 log CFU/ml [35], 7 - 8 log CFU/ml [36,37] in food products. The highest entrapment of the probiotic bacteria was found in the long-time process (12 h) conducted with 20 °Brix FTE for the PVOD and OD processes, while entrapment was decreased by the short-time process (6 h). In addition, using concentrated medium like 60 °Brix FTE resulted in lower entrapment as well. In the case of concentrated medium, the limitations of the viscous liquid with respect to tomato tissue, i.e., higher viscosity and lower inlet diffusion, were suspected. Moreover, high liquid concentration, in relation to lower water activity and higher osmotic pressure, might cause cell damage. Interestingly, probiotic entrapment could be promoted somewhat by vacuum, as shown in the process conducted with 60 °Brix FTE. A possible reason that explains the evidence is that vacuum pressure imposed on tomato tissue promotes a flow rate of osmotic solution and brings about feasible incorporation of a cell into the tomato tissue that provides a protective zone for the cells inside, while the remaining probiotic cells in the solution will be further damaged by the osmotic pressure of the concentrated medium. Therefore, a process limited to high solution concentration can take advantage of the PVOD process. The results of this study showed a high number of cell entrapments on the tomatoes that were in the range of 8 - 9 log CFU/g tomatoes. A high number of cells in the initial products and their stability during storage are important goals in the production of probiotic foods. Bertoret *et al*. [8] reported that Lactobacillus strains showed entrapment and reduced volume in dried apples depending on the type of impregnated liquid. Many factors influence survival rate probiotics after food processing (probiotic strain, pH, acidity, osmotic pressure, oxygen, water activity, temperature, protective agents, etc). In osmotic dehydration, protective ability depends on sugar type and concentration. Sucrose and thehalose were found to be good protective agents for preserving the dehydrated bacteria in low water activity [38]. In another work, the probiotics from MRS were again grown in fruit juice to meet the high cell concentration before applying the PVOD process that was conducted with only 10 min in the restoration step [13]. Therefore, a high concentration of biomass in the osmotic solution should be prepared. The probiotic number in tomatoes found in our work, which was carried out using an alternative method (longer restoration time), was similar to that reported in apple impregnated in mandarin juice [13], and guava and papaya impregnated in their juice [5].

Table 1 The ascorbic acid and lycopene contents (mg /100 g of tomatoes) of tomatoes after impregnation processes.

Treatment	Concentration (°Brix)	Impregnation	Time (h)	Ascorbic acid	Lycopene
1	20	OD	6	8.73±0.72^{a}	16.19±0.03^{c}
2	20	PVOD	6	7.63±0.64^{a}	16.18±0.14^{c}
3	20	OD	12	8.46±0.24^{a}	16.48±0.04^{abc}
4	20	PVOD	12	8.04±0.48^{a}	16.71±0.23^{a}
5	40	OD	6	7.90±0.42^{a}	16.21±0.44^{c}
6	40	PVOD	6	8.18±0.24^{a}	16.45±0.03^{abc}
7	40	OD	12	8.18±0.25^{a}	16.46±0.05^{abc}
8	40	PVOD	12	7.90±0.42^{a}	16.65±0.03^{ab}
9	60	OD	6	7.90±0.07^{a}	16.27±0.39^{bc}
10	60	PVOD	6	8.03±1.96^{a}	16.19±0.28^{c}
11	60	OD	12	7.94±0.80^{a}	16.08±0.03^{c}
12	60	PVOD	12	7.96±0.64^{a}	16.22±0.33^{c}

Different letters in the same column show significant differences ($p < 0.05$) by using the DMRT.

Table 2 The hardness values (g) of tomatoes after impregnation processes.

Treatment	Concentration (°Brix)	Impregnation	Time (h)	Hardness
1	20	OD	6	51.18±3.93^{bc}
2	20	PVOD	6	47.07±10.81^{bcd}
3	20	OD	12	46.63±6.24^{bcd}
4	20	PVOD	12	37.77±0.33^{d}
5	40	OD	6	40.74±5.19^{cd}
6	40	PVOD	6	48.82±1.58^{bcd}
7	40	OD	12	49.19±3.37^{bcd}
8	40	PVOD	12	63.65±3.11^{a}
9	60	OD	6	46.94±9.28^{bcd}
10	60	PVOD	6	54.14±10.11^{a}
11	60	OD	12	49.00±5.66^{bcd}
12	60	PVOD	12	58.58±5.11^{a}

^{a,b}Different letters show significant differences ($p < 0.05$) by using the DMRT.

Table 3 The color parameter values (g) of tomatoes after impregnation processes.

Treatment	Concentration (°Brix)	Impregnation	Time (h)	L^*	a^*	b^*	ΔE^*	Chroma
1	20	OD	6	64.04±0.19^{bc}	9.12±0.40^{c}	7.99±0.36^{bc}	8.78±0.54^{ab}	12.12±0.53^{d}
2	20	PVOD	6	63.07±0.88^{c}	12.78±0.75^{a}	11.25±0.25^{a}	4.34±1.04^{c}	17.03±0.73^{a}
3	20	OD	12	63.29±0.73^{c}	12.56±0.16^{a}	8.31±0.40^{b}	5.96±0.49^{bc}	15.06±0.35^{b}
4	20	PVOD	12	59.17±3.34^{d}	11.18±0.59^{b}	7.12±0.28^{c}	10.67±4.09^{a}	13.25±0.65^{cd}
5	40	OD	6	66.05±0.69^{ab}	12.69±0.18^{a}	7.99±0.54^{bc}	6.24±0.35^{bc}	15.11±0.31^{b}
6	40	PVOD	6	64.26±0.15^{bc}	12.98±0.23^{a}	7.53±0.23^{bc}	6.24±0.33^{bc}	15.01±0.31^{b}
7	40	OD	12	66.88±1.30^{a}	10.55±0.83^{b}	7.65±0.48^{bc}	8.19±0.55^{ab}	13.08±0.95^{cd}
8	40	PVOD	12	62.97±0.39^{c}	13.00±0.49^{a}	3.81±0.19^{d}	9.66±2.13^{a}	13.60±1.01^{c}
9	60	OD	6	66.05±1.00^{ab}	12.69±0.16^{a}	7.99±0.54^{bc}	8.67±0.45^{ab}	15.00±0.32^{b}
10	60	PVOD	6	63.66±1.08^{c}	13.38±0.50^{a}	7.54±0.25^{bc}	6.04±0.35^{bc}	15.36±0.30^{b}
11	60	OD	12	66.68±1.38^{a}	10.55±0.88^{b}	7.65±0.48^{bc}	9.48±1.43^{a}	13.03±0.95^{cd}
12	60	PVOD	12	62.28±0.60^{c}	12.98±0.50^{a}	2.85±0.97^{e}	10.46±1.12^{a}	13.05±0.45^{cd}

^{a,b}Different letters show significant differences ($p < 0.05$) by using the DMRT.

Table 4 *L. acidophilus* TISTR 1338 entrapment (log CFU/g tomatoes) on tomatoes after impregnation processes.

Treatment	Concentration (°Brix)	Impregnation	Time (h)	No. of *L. acidophilus* TISTR 1338
1	20	OD	6	8.89±0.06^{d}
2	20	PVOD	6	9.08±0.05^{bc}
3	20	OD	12	9.32±0.08^{a}
4	20	PVOD	12	9.29±0.09^{a}
5	40	OD	6	8.94±0.07^{cd}
6	40	PVOD	6	8.79±0.10^{d}
7	40	OD	12	9.10±0.14^{b}
8	40	PVOD	12	9.14±0.03^{b}
9	60	OD	6	8.47±0.10^{e}
10	60	PVOD	6	8.88±0.07^{d}
11	60	OD	12	8.58±0.10^{e}
12	60	PVOD	12	8.84±0.05^{d}

^{a,b}Different letters show significant differences ($p < 0.05$) by using the DMRT.

Conclusions

The advantage of PVOD over OD on mass transfer and product quality with respect to medium concentration and impregnation time is evident. Vacuum promoting mass transfer was clearly observed in the process using a short-time period. The impact of impregnation on lycopene degradation was minor compared to the impact on ascorbic acid content. A more than 50 % loss of ascorbic acid was found, starting at 10 g /100 g tomatoes of WL. Ascorbic acid and other active substances should be added to an osmotic solution to preserve product quality. Vacuum impregnation could preserve the color of the tomatoes in the low medium concentration and the short-time process. The effect of vacuum on probiotic cell entrapment varied depending on concentration and time. The highest entrapment of the probiotic bacteria was found in the long-time process (12 h) conducted with 20 °Brix FTE for the PVOD and OD processes, while entrapment was decreased by the short-time process (6 h). Using high solution concentration resulted in lower cell entrapment. The production of probiotic-enriched tomatoes using low solution concentration and short-time or the process using high solution concentration should be conducted by using vacuum pressure in order to increase the cell entrapment. These results will provide a platform that encourages the inclusion of probiotics in high quality fresh-cut products and semi-moist products. These products can then be considered as an alternative probiotic food choice for consumers.

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