Effect of Combined Processes of Osmotic Dehydration and Freezing on Papaya Preservation

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The effect of combined processes of osmotic dehydration and freezing on papaya pieces preservation was evaluated. Sucrose solutions were used as osmotic medium. Two multifactorial experimental designs, in two levels, were conducted consecutively to quantify the effect of the following factors: temperature, osmotic dehydration time, concentration of the osmotic medium and freezing rate. The response variables considered were: sensory evaluation, instrumental colour, instrumental texture, water activity (a_w), drip loss, and reducing and total sugars. The first experimental design selected fast freezing as the best process to preserve the texture of the fruit. From the second experimental design, under fast freezing, were obtained the following optimal levels: 65 °Bx for the concentration of the osmotic medium, 20 °C for the syrup temperature and 60 min for the osmotic dehydration time. An acceptability test was performed under these conditions with 100 potential consumers on a 7-point hedonic scale, which gave 98% acceptance. Glass transition temperature ($T_{g'}$) of the maximally cryoconcentrated liquid was −33.74 °C for the product processed under optimum conditions, which was the closest value to the common storage temperature (−18 °C) among all the measured samples.

Key Words: papaya, freezing, osmotic dehydration, glass transition, texture

INTRODUCTION

Freezing is a suitable way to preserve some quality parameters of foods, like colour, flavour, and nutrients. However, freezing and frozen storage almost always cause physical and chemical changes that lead to a loss of quality (Haard, 1997). This effect is more apparent in fruits or vegetables that have to be blanched or cooked to prevent enzymatic injury. High temperature processes destroy semi permeable membranes, which are essential to maintain turgescence and so water can diffuse into the tissue. This loss of compartmentalisation can produce unwanted chemical reactions among the components that normally are separated (Grout et al., 1991).

Most fruits do not require blanching, even so, those susceptible to enzymatic browning may benefit from inactivation of polyphenoloxidase (Haard, 1997). In particular, different varieties of papaya are consumed fresh, green or mature, or in salads. Also, mature papaya is often cooked for consumption (Paull, 1993) that it particularly convenient for the variety *Carica candamarcencis* Hook f. whose fresh tissue is hard and contains important amounts of the proteolytic enzyme papain.

Cryostabilisation is currently under active research as a means of protecting products stored for long periods at typical freezer temperatures (−18 °C) from deleterious changes in texture, structure and chemical composition (Slade and Levine, 1991). The procedure involves the incorporation of cryoprotectors (low molecular weight solutes) or cryostabilisers (high molecular weight solutes), with the aim to increase the glass transition temperature ($T_{g'}$) of the maximally cryoconcentrated liquid phase in the food (Martínez-Monzó et al., 1999). According to Slade and Levine (1991), the lower the difference between $T_{g'}$ and the storage temperature the higher the product stability.

The incorporation of these cryomaterials can be done through osmotic dehydration, i.e., by immersing the food in a hypertonic solution that contains the appropriate cryomaterial. During the osmotic dehydration the product is in contact with a low water activity solution in which a two-way mass transfer is established: water is transferred from the product to the solution, and in the opposite direction, solute is transferred from the solution to the product (Torreggiani, 1993; Spiazzi and Mascheroni, 1997; Salvatori and Alzamora, 2000). Afterwards, the food is frozen and will be characterized by higher $T_{g'}$ values when sugars of suitable molecular weight and structure are used as cryomaterials.

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Methods have been proposed to increase mass transfer during the osmotic dehydration such as vacuum osmotic dehydration (Fito and Chiralt, 1995), ultra high hydrostatic pressures (Rastogi and Niranjan, 1998) and high intensity electrical field pulse pretreatment (Rastogi et al., 1999). Nevertheless, thermal pretreatments such as blanching or cooking also increase mass transfer (Torreggiani, 1993).

The objective of this work was to study the preservation of papaya pieces (*Carica candamarcencis* Hook f.) through the combination of osmotic dehydration and freezing processes.

MATERIALS AND METHODS

Samples

Papaya fruits (*Carica candamarcencis* Hook f.) were cultivated in La Serena (Chile), provided by a local food processor and maintained at 12 °C until their processing. Physical and chemical characteristics of the fresh fruit are in Table 1. Commercial sucrose (IANSA, Chile S. A.) was used to prepare the osmotic syrup.

Experimental Design and Statistical Analysis

Two consecutive multifactorial experimental designs, in two levels, were performed to study simultaneously the effect of the factors that affect the combination of osmotic dehydration and subsequent freezing processes, through the following responses: sensory evaluation, colour, instrumental texture, water activity (a_w), drip loss and reducing and total sugars.

The first design was a diagnostic design, a fractional factorial of the type 2^{4-1}(Box et al., 1989) to study four factors: osmotic dehydration temperature (25 and 40 °C) and time (45 and 90 min), concentration of the osmotic medium (40 and 60 °Bx) and freezing rate (slow and fast). This design required 8 experimental runs (Table 2).

Based on results of the first design, a full factorial 2^3 design with two central points was performed (Box et al., 1989) with the following factors (Table 3): concentration of the osmotic medium (55 and 65°Bx); temperature (20 and 30 °C) and osmotic dehydration time (30 and 60 min).

Statistical analysis of the experimental data was done with the software Statgraphics Plus for Windows version 4.0 (Manugistics Inc., Statistical Graphics Corporation, Rockville, USA). The statistical significance of the effects was analyzed simultaneously by means of Normal Probability charts, Pareto charts and ANOVA ($p < 0.05$)

Table 1. Characteristics of fresh papaya fruits (*Carica candamarcencis Hook* f.).

Characteristics	Average ± SD
Weight (g)	144 ± 10.8
Length (cm)	8.3 ± 0.2
Soluble solids (°Bx)	3.0 ± 0.5
Reducing sugars (g/100 g)	2.0 ± 0.3
Total sugars (g/100 g)	2.8 ± 0.3
a_w	0.983 ± 0.06
Moisture (%)	91.0 ± 0.3
pH	4.7 ± 0.2
L^*	50.2 ± 2.6
a^*	− 3.6 ± 0.3
b^*	20.7 ± 1.2

Processing

Pre-treatment

The raw material was selected according to the following characteristics: regular size and uniform colour, firm texture and smooth external surface. The fruit was chemically peeled in a tap water solution containing 10% NaOH (Scharlau Laboratories, Barcelona, Spain) and 1% PI-30G (Química Norte Verde, La Serena, Chile) by immersion or 1.5 min at boiling temperature. The skin was eliminated by means of water showers and manual removal of residuals. The excess of NaOH remaining on the surface of the fruit was neutralized in a 2% citric acid solution (Cramer, Santiago, Chile) for 10 s. Then the fruit was cut into 5

Table 2. Standard matrix of the first experimental design (2^{4-1}).

Run No.	Concentration (*C*) (°Bx)	Temperature (*T*) (°C)	Freezing Rate* (*F*)	Time (*t*) (min)
1	40	25	Fast	45
2	60	25	Fast	90
3	40	40	Fast	90
4	60	40	Fast	45
5	40	25	Slow	90
6	60	25	Slow	45
7	40	40	Slow	45
8	60	40	Slow	90

*Fast = Cryogenic freezing; Slow = Air blast freezing.

Table 3. Standard matrix of the second experimental design (2^3).

Run No.	Temperature (*T*) (°C)	Concentration (*C*) (°Bx)	Time (*t*) (min)
9	20	55	30
10	30	55	30
11	20	65	30
12	30	65	30
13	20	55	60
14	30	55	60
15	20	65	60
16	30	65	60
17	25	60	45
18	25	60	45

longitudinal pieces along the largest axis, eliminating the ends of each piece (5 mm) and the inner seeds. The pieces were cooked at 98 °C in tap water for 20 min to soften the fruit and to inactivate proteolytic enzymes.

Osmotic Dehydration

Papaya pieces were cooled to room temperature (20 ± 1 °C) after cooking, fixed in a stainless steel basket between grids and immersed in sucrose solution prepared with tap water in a thermostatically controlled water bath (Blue M). The basket was mechanically rotated at 30 rpm to ensure a good mass transfer. The ratio of sucrose solution to papaya pieces was 6 : 1 (w/w). The concentration levels, osmotic dehydration time and temperature of the osmotic solution were determined through 2 experimental designs. The osmo-dehydrated pieces of papaya were stored at 4 °C for 24 h before freezing to homogenize the internal moisture and sugar concentration.

Freezing

Two freezing rates were used: a slow freezing rate in an air blast freezer (own manufacture) operating with air at − 28 °C and a velocity of 0.55 m/s during 1.5 h, and a fast freezing rate by means of a cryogenic freezer (CES model Box Freezer, Belgium) operating with liquid nitrogen at − 63 °C for 10 min. Frozen papayas were stored at − 18 °C for 15 days and thawed at room temperature (20 ± 1 °C) until equilibrating temperature previous to the analyses.

Design Responses

Sensory Evaluation

Twelve assessors (4 male and 8 female), aged between 22 and 35, were recruited and selected using International Standards (ISO, 1993) to participate in this study. This panel was trained additionally during six 2-h sessions for quantitative descriptive analysis (QDA) and quality of papaya pieces. The response variables were obtained by means of a quantitative descriptive analysis (QDA) on a 10 cm non-structured linear scale (Meilgaard et al., 1991), and a quality rating test (Muñoz et al., 1992) on a 7 point numerical scale (1 = very bad, 7 = very good). The following QDA descriptors and their respective anchor words were selected by panel consensus during the training period: colour intensity (pale yellow, dark yellow), specific papaya odour (none, intense), sweetness, (none, much) and hardness (soft, hard). The measured attributes of the quality-rating test were colour, flavour, texture and overall quality. Samples were randomly evaluated in 9 sessions (2 samples per session). Each assessor was provided with water to cleanse the palate between tastings.

Instrumental Colour

Colour was measured using a minolta Chroma Meter CR 200b (New Jersey, USA) attached to a data processor DP-100 using the CIE Lab L^*, a^* and b^* colour scale, calibrated with white and yellow tiles. Ten surface measurements on different papaya pieces were made under CIE D_{65} illuminant conditions, 0 ° viewing angle and a measuring area with a diameter of 8 mm.

Instrumental Texture

Texture was measured using a Texture Analyzer TA. interfaced with a data processor Texture Expert version 1.0 XT2i (Stable Microsystems, UK). A puncture test was carried out with a multiple puncture A/MC probe, known as multiple chip rig. This probe measures the average penetration force on 10 pieces simultaneously. Each piece is punctured with 2 probes (2 mm in diameter) at 2 cm from the end. A crosshead speed of 0.1 mm/s was used and three measurements were made. A bite jaw test was carried out using a Volodkevich HDP/VB jig, which performs an imitative test by simulating the action of an incisor tooth biting through food, at a crosshead speed of 0.5 mm/s with 5 measurements. The response variables considered for both tests were: initial slope, maximum rupture force and area under the curve (work).

Reducing and Total Sugars

The spectrophotometric 3,5 dinitrosalicylic acid method DNS (Miller, 1959) was used by measuring the absorbance in an 8453 UV-visible spectrophotometer (Agilent Technologies, California, USA) provided with an UV-visible Chem Station software. Measurements were made in triplicate.

Water Activity (a_w)

The a_w was measured at 25 °C with an electric hygrometer Humidat-IC (Novasina, Switzerland).

Drip Loss

Drip loss was measured according to Fuster et al. (1994). Results were reported as g of drained fluid per 100 g of sample. Analyses were performed in triplicate.

Other Analyses

Glass Transition Temperature

Differential scanning calorimetry (DSC) was performed in a TA Model 910 (TA Instruments, New Castle, USA) on selected samples of the second experimental design (runs 11, 17, 18 and control) with final moisture contents of approximately 0.72, 0.71, 0.82 and 0.91 g of H_2O/g sample (w.b.), respectively. The procedure described by Anglea et al. (1993) was employed. Analyses were performed in duplicate.

Moisture

Moisture was determined in a vacuum oven until constant weight according to AOAC 920.151 (AOAC, 1990). Analyses were performed in duplicate.

Product Acceptability

Acceptability was measured on papaya pieces obtained under the best conditions found in the optimisation process with 100 frequent papaya consumers on a 7-point hedonic scale (1 = dislike it very much, 7 = like it very much).

RESULTS AND DISCUSSION

First Experimental Design

Freezing rate (factor F) was the most significant effect on the responses of the first design (Table 6), getting the best responses for under fast freezing rather than slow freezing, especially regarding sensory quality (flavour, texture and overall quality), instrumental texture (maximum strength and area) and water activity. From slow to fast freezing rate improved the overall quality of the product in 16.5% (Table 5).

Concentration, temperature and osmotic dehydration time affected a low number of responses and, practically, no significant interaction effects were found. Responses mostly affected were: bite jaw maximum strength, which increased 57% with increasing osmotic dehydration time; texture quality, which increased 9.3% with increasing concentration; and specific papaya odour, which decreased 32% with temperature increase.

Fast freezing preserved to a larger extent sensory quality and firmness of the product, because it produced lower cellular damage due to formation of relatively smaller ice crystals. Slow Frozen samples exhibited a larger drip and a higher water activity compared to fast frozen samples (Table 4). This is reasonable because a

Table 5. Percent change in the response by switching from slow to fast freezing.

Response	Variable	Response Change (%)
Sensory Quality	Flavour quality	19.8
	Texture quality	11.1
	Overall quality	16.5
Bite Jaw Test	Maximum force	20.5
	Area	25.0
Water Activity	a_w	– 1.71

Table 4. Effects of the first fractional factorial experimental design (2^{4-1}).

			Effects					
	Response	Average	Concentration (*C*)	Temperature (*T*)	Freezing rate (*F*)	Time (*T*)	$(CF+Tt)^1$	SD
Sensory Descriptive Test2 (QDA)	Yellow colour intensity	4.1	– 0.6	– 1.6	– 0.5	– 1.5	–	1.5
	Sweetness	5.3	1.0	1.1	– 1.1	0.6	–	1.7
	Odour	3.7	0.6	– 1.4 (*)	– 0.8	– 0.7	–	0.8
	Hardness	5.2	0.2	– 0.2	0.4	0.2	–	1.9
	Colour quality	5.0	– 0.3	– 0.6 (*)	– 0.3	– 0.6 (*)	–	0.5
Sensory Quality[3]	Flavour quality	5.0	0.5	0.4	– 1.1*	0.5	–	0.6
	Texture quality	5.1	0.5 (*)	0.2	– 0.6 (*)	0.4 (*)	–	0.2
	Overall quality	5.0	0.3	0.1	– 0.9 (*)	0.4	–	0.5
	*L**	52.04	– 0.26	1.40	1.47	0.33	–	3.91
Colour	*a**	– 2.07	0.49	– 0.06	0.72	0.27	–	0.83
	*b**	28.71	0.87	0.81	– 1.08	2.08	–	6.23
	Initial slope (N/mm)	1.39	– 0.08	– 0.13	– 0.38	0.48	–	0.73
Bite Jaw Test	Maximum force (N)	8.07	– 0.27	– 1.97 (*)	– 1.84 (*)	3.58 (*)	2.78	0.50
	Area (N mm)	62.27	– 0.74	– 11.81	– 13.86 (*)	21.31 (*)	16.46	12.23
	Initial slope (N/mm)	3.74	– 0.63	0.38	– 1.41	1.18	–	1.74
Puncture Test	Maximum force (N)	22.05	– 3.31	– 1.58	– 5.17	– 1.06	–	18.63
	Area (N mm)	254.90	– 14.18	– 25.57	– 59.57	51.32	–	80.12
	Total, (%)	22.61	– 0.88	3.18	– 4.05	0.00	–	14.00
Sugars	Reducing, (%)	1.61	0.28	– 0.62	– 0.58	0.41	–	1.09
a_w	Water activity	0.930	0.004	– 0.001	0.016 (*)	– 0.010	–	0.017
Drip	Weight loss%	2.50	0.65	– 0.70	0.80	– 0.55	–	3.43

*($P<0.05$).
[1]Excluded effect to estimate the grouped standard deviation for the effects.
[2]Values based on a descriptive scale of 10 cm length.
[3]Values based on a sensory 7-point quality scale.

Table 6. Effects of the second full factorial experimental design (2^3).

	Response	Average	Effects Temperature	Concentration	Time	SD
Sensory Descriptive Test[1] (QDA)	Yellow colour intensity	4.9	0.7	1.0	1.2 (*)	0.5
	Sweetness	5.6	1.0	0.8	1.8 (*)	0.4
	Odour	4.3	0.2	0.6	−0.5	0.4
	Hardness	5.2	−0.1	−0.8	0.9	0.5
Sensory Quality[2]	Colour quality	5.9	0.1	0.4	0.6 (*)	0.2
	Flavour quality	5.5	0.4	0.5	0.2	0.2
	Texture quality	5.1	0.2	0.6 (*)	−0.2	0.2
	Overall quality	5.3	0.3	0.4	0.1	0.2
Colour	L^*	49.12	−1.09	−1.22	−0.58	1.98
	a^*	−3.05	0.33	0.42	0.28	0.25
	b^*	26.92	0.33	1.32	0.45	1.29
Bite Jaw Test	Initial slope (N/mm)	2.10	−0.29	−0.24	−0.47	0.68
	Maximum force (N)	9.19	−1.54	0.13	−0.97	3.21
	Area N mm	60.28	−9.54	−0.16	−4.98	14.9
Puncture Test	Initial slope N mm	9.16	0.36	−0.33	0.21	0.85
	Maximum force (N)	46.02	2.24	−4.14	2.57	6.49
	Area (N mm)	249.30	−20.99	−9.78	−0.38	38.29
Sugars	Total (%)	18.83	1.88	0.84	3.06	1.72
	Reducing (%)	1.71	−0.17	−0.07	0.35	0.34
a_w	Water activity	0.95	−0.05	0.09	−0.06	0.05
Drip	Weight loss (%)	4.94	−0.11	−0.67	0.21	1.73

[1]Values based on a descriptive scale of 10 cm length.
[2]Values based on a sensory 7-point quality scale.
(*) $P<0.05$.

slow freezing procedure causes extracellular growth of large ice crystals (Aguilera and Stanley, 1990) whose effect on membrane disruption makes a higher proportion of solution to drain from the cells. However, if damage is limited, water could diffuse back to the cells (Grout et al., 1991). In this study, drip amount was not significant, probably due to a massive cellular damage produced during the previous thermal treatment stage. Nevertheless, a_w showed a significant increase, which might be a consequence that at high moisture content, and due to the shape of the sorption isotherms of fruits, a small change in the surface moisture content resulting from dripping may result in an important a_w change.

In instrumental texture measurement, a temperature increase produced a statistically significant change only in the bite jaw maximum strength test due to tissue softening. The effect of fast freezing was significant for the responses hardness and mechanical work (area under the curve) of the bite jaw tests, as expected because fast freezing produces less damage in cellular structure. Increasing osmotic dehydration time increased product hardness, as a consequence of larger water drainage from the product simultaneously with an increasing uptake of solids.

Second Experimental Design

Given the previous results, a second design was carried out, in which fast freezing was chosen for all runs. The levels for the factors temperature (T) and osmotic dehydration time (t) were adjusted around the minimum value of the previous design and concentration values (C) around the maximum value (Table 6). The factor temperature was not statistically significant over any response, and an increase in osmotic dehydration time resulted in yellow colour intensity, colour quality and sweetness. The factor concentration was significant over the sensory texture quality, with an improvement at high levels. With these significant effects, it was possible to obtain the following linear models in coded variables:

$$\text{Yellow colour intensity} = 4.9 + 0.6t \quad (1)$$

$$\text{Colour quality} = 5.9 + 0.3t \quad (2)$$

$$\text{Sweetness} = 5.6 + 0.9t \quad (3)$$

$$\text{Texture quality} = 5.1 + 0.3C \quad (4)$$

Yellow colour intensity and colour quality increased with increasing osmotic dehydration time as shown in Equations (1) and (2) due to the concentration of surface carotenoids as a result of the osmotic dehydration, this caused more intense and characteristic colour, which is a decisive quality factor for this type of products.

Sweetness was affected by osmotic dehydration time (Equation (3)) because the sugar diffusion into the fruit prevailed over the water loss from the fruit into the solution.

Table 7. Grouped standard deviation of instrumental response measurements of both designs.

	First Experimental Design		Second Experimental Design	
Response	SD_1	$d.f._1$	SD_2	$d.f._2$
*L**	2.7	72	4.4	90
*a**	0.5	72	0.6	90
*b**	2.4	72	2.9	90
Bit slope Test				
Slope	0.3	32	0.3	40
Force	1.7	32	1.0	40
Area	4.3	32	5.5	40
Puncture Test				
Slope	0.1	16	0.5	20
Force	4.3	16	1.5	20
Area	5.3	16	6.2	20
Total sugars	0.30	16	0.33	20
Reducing sugars	0.02	16	0.04	20
a_w	1.4	8	1.0	10
Drip	2.0	16	3.0	20

Table 8. Consumer acceptability of the optimum product.

	Proportion of Consumers (%)				
Sensory Acceptability[1]	Colour	Odour	Flavour	Texture	Overall Acceptability
Rejection	4	2	1	5	0
Indifference	2	4	1	3	2
Acceptation	94	94	98	92	98

[1]Based on a 7-point hedonic scale (7 = like it very much, 1 = dislike it very much), grouped as rejection (score 1–3), indifference (score 4) and acceptation (score 5–7).

Table 9. $T_{g'}$ values of osmodehydrofrozen papaya (runs 11, 17, 18) and fast frozen control treatment.

RunsR	Process Description	$T_{g'}$ (°C)
BC	Cryogenic Control	− 45.52 ± 0.33
18	55 °Brix, 20 °C, 30 min	− 36.64 ± 0.08
11	55 °Brix, 20 °C, 60 min	− 34.67 ± 0.19
17*	65 °Brix, 20 °C, 60 min	− 33.74 ± 0.12

*Optimum treatment.

Texture quality increased with concentration (Equation (4)) due to solid diffusion into the fruit and water loss from the fruit.

From the significant factors shown in Table 6 and the linear models obtained, the levels selected for the best process conditions were: high concentration of the osmotic medium (65 °Bx) and high osmodehydrating time (60 min). Since dehydrating temperature was not significant, a temperature of 20 °C was chosen considering a practical and economical point of view. At these optimum levels, sensory attributes of colour quality and texture quality exhibited a value of 6.2 (good) and 5.4 points (fairly good), respectively.

Comparison of Both Designs

There was a great similarity between the average responses obtained in both experimental designs, which indicates a good reproducibility of the experimental information (Tables 4 and 6). For example, the average for hardness and texture quality were almost identical for both designs (5.2 and 5.1, respectively). Differences between the first and second design were related mainly to texture, as can be seen in slope (3.74 vs. 9.16) and maximum strength (22.05 and 46.02) in the puncture test, which might be mainly due to the effects of the different freezing rates.

The average of each sensory response increased from the first to the second experimental design; for example, colour quality increased from 4.9 to 5.9 points and sweetness changes from 5.3 to 5.6 points, which can be attributed to a correct choice of the factor levels for the second design, as well as the elimination of freezing rate as a source of variability.

The standard deviation of the effects was higher in the first experimental design than in the second experimental design for almost all response variables, which reflects that freezing rate is a source of large variation (Table 7).

Acceptability Evaluation

The product obtained under the optimum conditions showed a general acceptability of 98% of a total of 100 interviewed consumers (Table 8).

Effect of $T_{g'}$ on the Stability and Quality of Frozen Papaya

The control treatment (only cooked and fast frozen, without osmotic dehydration) had a $T_{g'}$ value of − 45.5 °C, that was much lower than the $T_{g'}$ value of the osmodehydrofrozen samples (Table 9). This can be explained by the intake of sucrose during the osmotic dehydration process. The optimum treatment had a $T_{g'}$ value of − 33.74 °C, which was closer to the common freezing storage temperature of − 18 °C, which could indicate a better stability of the product under those storage conditions. Therefore, we consider more research is needed to study the relationship between stability and glass transition temperature.

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REFERENCES

AOAC (1990). *Official Methods of Analysis*. Washington, D.C: Association of Official Analytical Chemists.

Aguilera J.M. and Stanley D.W. (1990). *Microstructural Principles of Food Processing and Engineering*. London: Elsevier Applied Science. pp 71–75.

Anglea S., Karathanos V. and Karel M. (1993). Low temperature transition in fresh and osmotically dehydrated plant materials. *Biotechnology Progress* **9**: 204–209.

Box G.P, Hunter W.G. and Hunter J.S. (1989). *Estadística para experimentadores. Introducción al Diseño de experimentos, análisis de datos y construcción de modelos*. Barcelona: Reverté. pp. 385–424.

Fito P. and Chiralt A. (1995). An update on vacuum osmotic dehydration. In: Barbosa-Cánovas G.V. and Welti-Chanes J. (eds.), *Food Preservation by Moisture Control. Principles and Applications*. Lancaster, PA: Technomic Publishing Co. pp. 351–374.

Fuster C., Prestamo G. and Cano M.P. (1994). Drip loss, peroxidase and sensory changes in kiwi fruit slices during frozen storage. *Journal of the Science of Food and Agriculture* **64**: 23–29.

Grout B.W, Morris G.J. and Mc Lellau M.R. (1991). Freezing of fruit and vegetables. In: Bald W.B. (Ed.), *Food Freezing Today and Tomorrow*. London: Springer-Verlag. pp. 113–121.

Haard N.F. (1997). Product composition and the quality of frozen food. In: Erickson M.C. and Hung Y. (eds.), *Quality in Frozen Food*. New York: Chapman and Hall. pp. 275–289.

ISO (1993). *Sensory Analysis*: *General Guidance for the Selection*, *Training and Monitoring of Assessors*. ISO 8586-I. Geneva: ISO.

Martínez-Monzó J., Martínez-Navarrete N., Chiralt A. and Fito P. (1999). Mechanical and structural changes in apple (var. Granny Smith) due to vacuum impregnation with cryoprotectants. *Journal of Food Science* **63**: 499–503.

Meilgaard M., Civille G.V. and Carr B.T. (1991). *Sensory Evaluation Techniques*. 2nd Edn. Boca Ratón: CRC Press Inc. pp. 187–200.

Miller G.L. (1959). Use of dinitrosalicylic acid reagent for determination of reducing sugar. *Analytical Chemistry* **31**: 426–XX.

Muñoz A.M., Civille G.V. and Carr B.T. (1992). *Sensory Evaluation in Quality Control*. New York: Van Nostrand Reinold. pp. 108–139.

Paull R.E. (1993). Pineapple and papaya. In: Seymour G.B., Taylor J.E. and Tucker G.A. (eds.), *Biochemistry of Fruit Ripening*. London: Chapman and Hall. pp. 291–314.

Rastogi N.K. and Niranjan K. (1998). Enhanced mass transfer during osmotic dehydration of high pressure treated pineapple. *Journal of Food Science* **63**: 508–511.

Rastogi N.K., Eshtiaghi M.N. and Knorr D. (1999). Accelerated mass transfer during osmotic dehydration of high intensity electrical field pulse pretreated carrots. *Journal of Food Science* **64**: 1020–1023.

Salvatori D. and Alzamora S.M. (2000). Structural changes and mass transfer during glucose infusion of apples as affected by blanching and process variables. *Drying Technology* **18**: 361–382.

Slade L. and Levine H. (1991). Beyond water activity: recent advances based on and alternative approach to the assessment of food quality and safety. *Critical Reviews of Food Science and Nutrition* **30**(2–3): 115–360.

Spiazzi E. and Mascheroni R. (1997). Mass transfer model for osmotic dehydration of fruits and vegetables-I. Development of the simulation model. *Journal of Food Engineering* **34**: 387–410.

Torreggiani D. (1993). Osmotic dehydration in fruit and vegetable processing. *Food Research International* **26**: 59–68.