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Effect Of Freeze-Thaw Pretreatment On Mass Transfer And Overall Acceptability Of Osmo-Convectively Dehydrated Carrot Slices

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Abstract:
Osmo-convective dehydration is one of the combo-drying techniques for shelf stable dehydrated products. Usually dried carrots are used in soups, curries, pastries, sauces and other types of ready-made meals. But for direct consumption of osmo-dehydrated products, it is pre-requisite to have desirable mass transfer and sensory properties of final products. Pre-treatments play an important role to enhance mass transfer and maintain sensory quality. Hence the present investigation was carried out to assess the effect of freeze-thaw pre-treatment on quality of osmo-convectively dehydrated carrot slices. Steam blanched carrot slices were frozen and thawed at different freezing and thawing temperature before osmo-convective dehydration. The effect of freezing and thawing temperature on mass transfer kinetics after osmosis and colour, texture (hardness), apparent density, shrinkage ratio, loss of shrinkage and sensory parameters after convective drying of osmosed carrot slices were evaluated. Sugar gain and water loss of pre-treated carrot slices increased with an increase in freezing and thawing temperature. Freezing and thawing treatment caused a significant reduction in hardness of final product. Lower freezing and thawing temperature resulted in higher percentage of shrinkage ratio as comparative to higher temperature of freezing and thawing. Lowest apparent density (1.211 g/ml) was recorded for the osmo-convectively dehydrated carrot slices prepared at lower freezing and thawing temperature. Osmo-convectively dehydrated carrot slices prepared by using -25° C freezing and 5° C thawing temperature resulted in desirable mass transfer, retention of hardness, lower loss of shrinkage (%) and highest score for all sensory parameters.

Key words: *Blanching, Freeze-thaw pre-treatment, Osmotic dehydration, Mass transfer, Hardness, Sensory acceptance.*

Introduction

Carrot (Daucus carota L) is high-value crop loaded with nutritional benefits and has unique place in human diet. Carrot is an excellent source of vitamin A, and loaded with α and ß carotene. It also contains sodium, potassium, calcium, iron, magnesium, phosphorus, and fiber [1]. Although carrot is a seasonal crop, its availability throughout the year is increasing day by day. During a glut in the market, there is sudden fall in the prices and being a high moisture crop, it is perishable and has short shelf life. Dehydration is one of the important preservation methods to develop different value added products during the main growing season. Besides extending the shelf life and providing a wide range of foods to consumers, drying reduces the bulk and thereafter helps to lower down the cost during transportation and storage. Osmotic dehydration is one of convenient dehydration method widely used for water removal across permeable membrane from high potential to low water potential by immersion in concentrated solution of sugar, salt, acid etc. It also helps to improve economics of dehydration process [2, 3]. During osmosis, simultaneously countercurrent solution flows with a combination of drying, leaching, and impregnation processes occurring in biological tissue matrix [4]. Pretreatment before osmotic dehydration such as blanching, freezing, thawing, ultrasound, high pressure, and high intensity pulsed electric field have been reported to enhance mass transfer rates [5, 6]. It also helps to prevent the loss of nutritional, sensorial, textural and functional properties of dehydrated fruits and vegetable without changing its integrity.

Freezing is another pre-technique for osmotic dehydration of fruit and vegetable by significantly enhancing mass transfer during osmotic process and has influence on changing tissue structure. It also assists in degassing as well as increasing the permeability of the cells which increases diffusivity of solutes [7, 8]. Freezing and thawing treatments could induce a highly porous structure which is desirable for texture of dehydrated fruits and vegetable products. Freezing and thawing temperature plays a significant role on mass transfer kinetic as well as shrinkage of products. Therefore, the present investigation was planned to assess the effect of freezing and thawing temperature on quality of osmo-convectively dehydrated carrot slices.

Materials and Methods

Sample preparation

The fresh, healthy carrots were procured from local market of Parbhani. Cleaned and washed carrots were sliced into circular discs of 3 mm thickness. Slices were steam blanched for 2 minutes. Based on earlier research work and preliminary trials, levels of freezing temperature were decided as -5, -15 and -25° C and thawing temperature as 5, 15 and 30° C [9, 10]. The pre-blanched carrot slices were frozen for -5, -15 and -25 °C temperature. Freezing was carried out until the temperature at centre of carrot slices reaches to required level as per treatments in an air blast freezer. Then thawing was carried out at 5, 15 and 30° C temperature as per experimental plan.

Control (without freeze-thaw treatment) sample and all freeze-thaw pretreated carrot slices were osmo-dehydrated in sugar solution of 50 °Brix concentration using slice to solution ratio of 1:4. Solution temperature of 50° C was maintained during osmotic dehydration process [11, 12]. The carrot slices were taken out from sugar solution after four hours, and excess syrup was removed by using tissue paper. Osmotically dehydrated slices were convectively dried at 60° C in tray dryer up to 6% (w.b.) moisture content.

Quality assessment

The effect of freezing and thawing temperature on different quality parameters of osmo-convectively dehydrated carrot slices was assessed in terms of mass transfer kinetics after osmosis and colour, texture (hardness), apparent density, shrinkage ratio, loss of shrinkage and sensory parameters after convective drying. Experimental data were subjected to Analysis of Variance (ANOVA) in OPISTAT software.

Mass transport parameters

Mass transport parameters of osmo-dehydrated carrot slices were determined in terms of water loss, solid gain and weight reduction [13]. Water loss is determined as net loss of water from sample per hundred grams of fresh carrot slices. Sugar or solute gain is the uptake of solids by food sample from osmotic solution during osmosis. Weight or mass reduction is the net reduction in the weight of fresh carrot slices per hundred grams of fresh carrot slices.

$$\text{Water loss (\%)} = \frac{wiXi - wfXf}{wi} \times 100$$

$$\text{Solid gain (\%)} = \frac{\{[\![wf(1-Xf)/100]\!] - [\![wi(1-Xi)/100]\!] \times 100\}}{wi}$$

$$\textbf{WR} \text{ (\%)} = \text{WL (\%)} - \text{SG (\%)}$$

Where,
w_{i}- = Initial weights (time t) of samples (g),
w_f = Final weights (time t) of samples (g)
Xi = Initial moisture content (time t) of samples
Xf = Final moisture content (time t) of samples, respectively.

Apparent density

The apparent density of the osmo-dehydrated carrot slices was determined using following expression [14].

$$\rho_a = m/v_a$$

Where, m - Mass of osmo-convectively dried carrot slices (g),
Va- Apparent volume osmo-convectively dried carrot slices (ml)

Percentage of shrinkage ratio

The percentage of shrinkage ratio (SR) of final dried carrot slices was calculated using following equation [15].

$$SR = (V_t/V_0) \times 100$$

Where,
V_t -- Volume of carrot slices after osmo-convectively drying slices, ml
V_0-- Volume of carrot slices before osmo-convective drying (raw/ fresh carrot slices), ml

Loss of shrinkage

The loss of shrinkage was calculated using following equation [16].

$$\text{Loss of shrinkage} = [\,1- (V_t/V_0)] \times 100$$

Where,
V_t - The apparent volume of osmo-convectively dried carrot slices, ml
V_0 - Initial apparent volume of fresh slices, ml

Objective evaluation of Texture (Hardness) and Colour

The textural property i.e. hardness of osmo-convectively dehydrated carrot slices were determined by measuring the force (Kg) needed to compress the osmo-convectively dehydrated carrot slices using Texture Analzer (Model: TA-XT plus, Stable Micro System, UK) equipped with 50 kg load cell. The colour of osmo-convectively dehydrated carrot slices was evaluated using a Hunter Lab Colour Analyzer-Labscan-2 (Hunter Associates Laboratory, Inc. Virginia, USA) in terms of L*, a*, and b* values.

Total colour difference, croma and hue angle

Total colour difference (TCD) is a function of the three L* a* and b* coordinates. Hue angle provides more information about the spatial distribution of colour where as chroma indicates more vivid nature of colour. Total colour difference (ΔE), chroma (ΔC) and hue angle (ΔH) were calculated according to the following formula [17]. Where L_o*, a_o*, and b_o* denote the color parameters of fresh carrot slices and L*, a*, and b* correspond to values of final osmo-convectively dried RTE carrot slices.

$$\Delta E = [\,(L_o^* - L^*)^2 + (a_o^* - a^*)^2 + (b_o^* - b^*)^2]^{1/2}$$

$$\text{Chroma } (\Delta C) = ((a^{*2} + b^{*2})^{1/2})$$

$$\text{Hue angle } (\Delta H) = (\tan^{-1} b^*/a^*)$$

Subjective/ sensory evaluation

A panel of semi-trained participants used the standard method (ISI) to evaluate the sensory attributes of carrot slices prepared by varying the freezing and thawing time at different thawing condition (1971a-1971b) using 9-point Hedonic scale. The numerous quality factors, such as colour, appearance, texture, taste, favour and overall acceptability were considered for evaluation.

Result and Discussion

Mass transport parameters

The mass transport data (Table 2, Fig. 1) of osmo-dehydrated carrot slices as affected by freeze–thaw treatment was significantly differed for different freezing and thawing temperature. Significantly highest sugar gain (39.53

%) and water loss (24.11 %) was recorded for treatment frozen at -5° C and thawed at 30° C temperature while lowest sugar gain (18.03 %) and water loss (16.37 %) was found for control sample. All freeze–thawed samples had the higher sugar gain and water loss than control. Similar trend in high sugar uptake by pre-frozen sample than unfrozen was observed during osmotic dehydration of apple slices enhancing the permeability of cell membranes, and leading to increase the diffusivity of solutes [18]. Treating sample prior to osmotic dehydration assisted in degassing as well as increasing the permeability of the cells [7, 19]. Hence, freeze-thaw pre-treatment resulted in higher flow of osmo-active substance that further increased the solid uptake.

Table 1: Experimental treatment

Treatments	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_0
Freezing temperature (°C)	-5	-5	-5	-15	-15	-15	-25	-25	-25	Control sample (without freeze-thaw treatment)
Thawing temperature (°C)	5	15	30	5	15	30	5	15	30	

Table 2: Effect of freezing and thawing pretreatment on mass transport of osmo-dehydrated carrot slices

Treatment	Sugar Gain (%)	Water Loss (%)	Weight Reduction (%)
To	18.03	16.37	-01.66
T_1	37.23	22.19	-15.04
T_2	38.62	23.33	-15.29
T_3	39.53	24.11	-15.42
T_4	34.36	19.78	-14.58
T_5	36.38	21.46	-14.92
T_6	37.25	22.19	-15.06
T_7	33.13	18.68	-14.45
T_8	34.71	19.85	-14.86
T_9	35.26	20.43	-14.83
SE	0.406	0.369	0.072
CD	1.217*	1.104*	0. 214*

* --5 % level of significance

Higher freezing temperature of -5° C resulted into higher sugar gain and water loss of 39.13 and 26.09 %, respectively for 30° C thawing temperature. While lowest solid gain and water loss were recorded for -25° C freezing temperature followed by -15° C. The slow freezing of cellular tissues lead to formation of large extracellular ice crystals that might cause more mechanical damage and resulted in higher solid uptake, while rapid freezing leads to low solid gain due to nucleation and formation of many smaller crystals [20].

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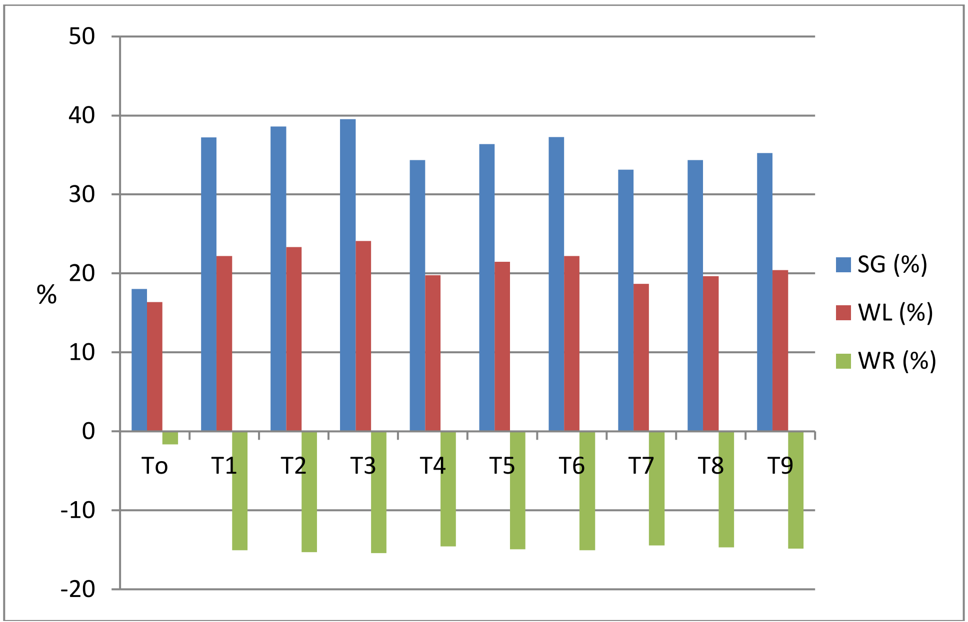

Fig. 1: Effect of freezing and thawing pretreatment on mass transport of osmo-dehydrated carrot slices

here was an increasing trend in solid gain and water loss with increase in freezing and thawing temperature which was in accordance with the observation for red bell peppers during osmotic dehydration [19]. Negative weight reductions are at the cost of higher solid gain than water loss due to blanching and freezing pre-treatments. However non-significant difference in weight reduction was observed between 15° C and 30° C thawing temperatures for all three freezing temperature.

Hardness

The hardness of osmo-convectively dried carrot slices as influenced by freeze-thaw treatment were determined to optimize the freezing and thawing temperature and found significance. Hardness value ranged from 3.43 kg to 6.05 kg within the treatments under experimental range. Hardness of control sample was significantly higher than pre-treated osmo-convectively dehydrated carrot slices (Table 3). Freezing as well as thawing treatments caused a significant reduction in hardness of final product. Significantly lower hardness of carrot snacks was observed for pre-frozen sample than unfrozen [21]. Significantly lowest hardness (3.43 kg) was recorded for sample which was frozen at -5 and thawed at 30° C temperature while highest value of hardness (6.05 kg) was observed for control sample.

Table 3: Effect of freezing and thawing temperature on hardness, apparent density and percentage of shrinkage ratio of osmo-convectively dehydrated carrot slices

Treatment	Hardness (kg)	Apparent density (g/ml)	Percentage of Shrinkage Ratio (%)	Loss of Shrinkage (%)
To	6.05	1.881	31.12	68.88
T_1	3.89	1.693	38.17	61.83
T_2	3.67	1.710	36.58	63.42
T_3	3.43	1.769	36.14	63.86
T_4	4.16	1.593	42.13	57.87
T_5	3.83	1.621	41.06	58.94
T_6	3.69	1.686	40.82	59.18
T_7	4.57	1.211	43.75	56.25
T_8	4.38	1.280	42.44	57.56
T_9	4.23	1.303	41.38	58.62
SE	**0.059**	**0.004**	**0.342**	**0.356**
CD	**0.179***	**0.011***	**1.025***	**1.069***

*-5% level of significance

Lower freezing temperature i.e. -25° C resulted in higher value of hardness (4.57 kg) than carrot slices frozen at -15° C and -5° C temperature for 5° C thawing temperature. Similar changes were observed in hardness for dehydrated carrot [22]. Higher hardness value for lower freezing temperature might be due to the less tissue damage and a homogeneous porous structure than sample frozen at higher freezing temperature which presented the biggest pores and structural collapse in the sample images by Scanning Electron Microscopy (SEM) [23]. Slow freezing might lead to significant cell dehydration and formation of large extracellular ice crystals resulting in more cell separation, rupture and destruction of membrane than rapid freezing [24]. Hence, higher freezing rates produce smaller ice crystals and less breakage of cell walls, and consequently less texture damage. Moreover, lower hardness values were found for higher thawing temperature. Slight reduction in hardness was noted during increase in thawing temperature for all freezing temperature. De-compartmentalization caused by ice crystals prevented the return of water to the intracellular medium during thawing at higher temperature causing loss of turgidity which resulted in lower hardness [6].

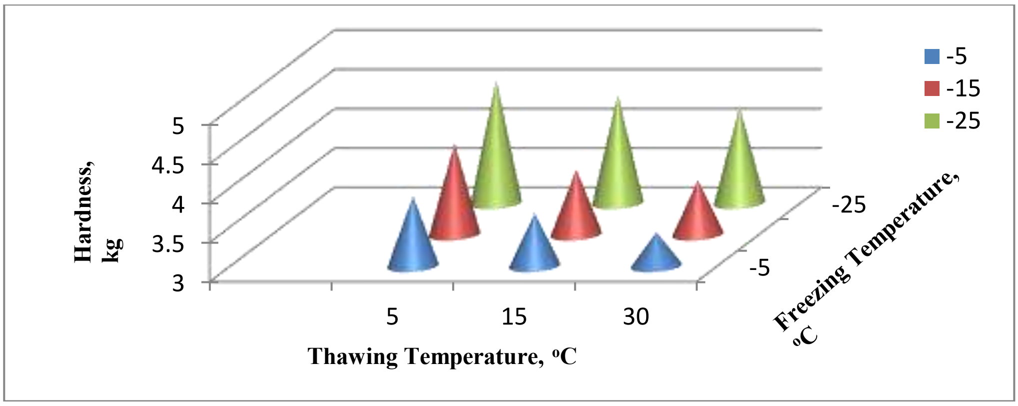

Fig. 2: Effect of freezing and thawing temperature on hardness of osmo-convectively dehydrated carrot slices

Apparent density and percentage of shrinkage ratio

The osmo-dehydration as well as mechanical drying usually results in smaller size of final product than its original fresh form. The shrinkage in volume depends upon the density of final product. The effect of freeze-thaw pre-treatment on the volumetric character of final osmo-convectively dried carrot slices was evaluated and data regarding these parameters is presented in Table 3. Apparent density of final dried carrot slices was found statistically significant and ranged from 1.881 to 1.303 g/ml within experimental range. However, lowest apparent density i.e. 1.211 g/ml was recorded for -25° C freezing and 5° C thawing temperature. Lower thawing temperature also resulted in lower apparent density. Lower apparent density was an indication of lower shrinkage by higher retention of volume in dried candied pumpkin [14]. Control slices without freeze-thaw treatment showed maximum value of apparent density resulting higher reduction in volume of dried carrot slices. Similar low apparent density indicating a great volume of pores formed (porous final product) was noted during the drying process of tuna [25].

The higher value of percentage of shrinkage ratio is desirable for better quality of dried products. Percentage of shrinkage ratio and loss of shrinkage was significantly lower and higher, respectively for unfrozen (control) sample than that of all pre-treated samples. However, more shrinkage was found in unfrozen. Lower freezing and thawing temperature resulted in higher percentage of shrinkage ratio and lower loss of shrinkage as comparative to higher temperature of freezing and thawing. The possible reason for higher shrinkage ratio and lower loss of shrinkage might be due to better porous structure for lower freezing temperature. Similar trend of less tissue damage and a homogeneous porous structure of banana samples was recorded for lower freezing temperature which resulted in higher retention of volume [23]. Round cell micrographs similar to fresh tissue was obtained for fast freezing of mango cell wall instead decrease in cell uniformity and larger changes in cellular structure for slow freezing [26].

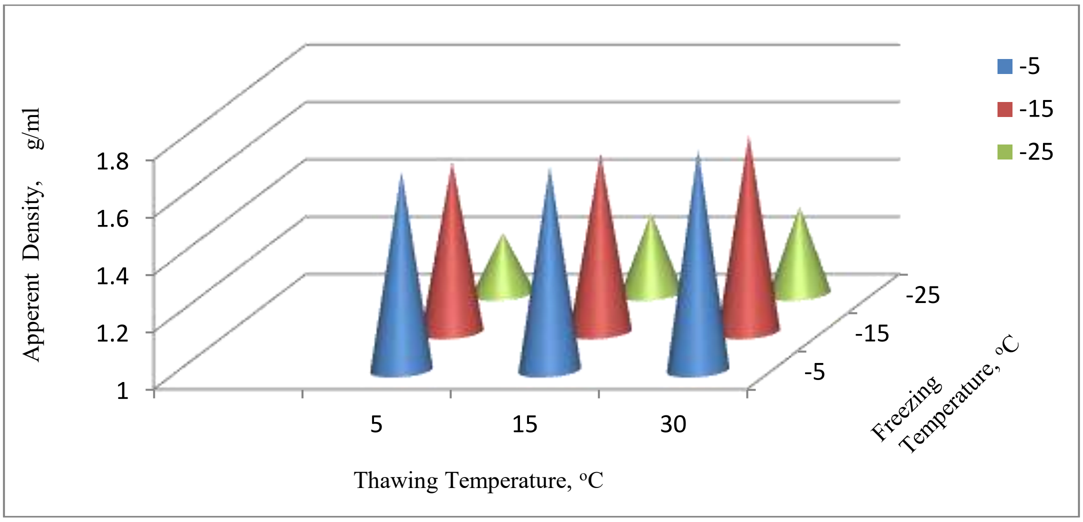

Fig. 3 (A)

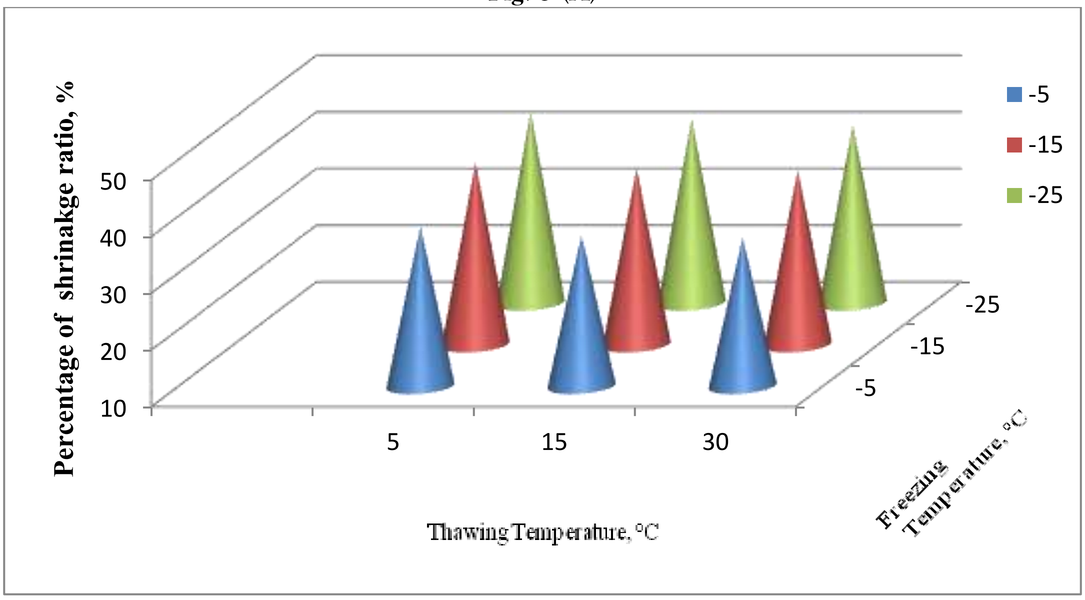

Fig. 3 (B)

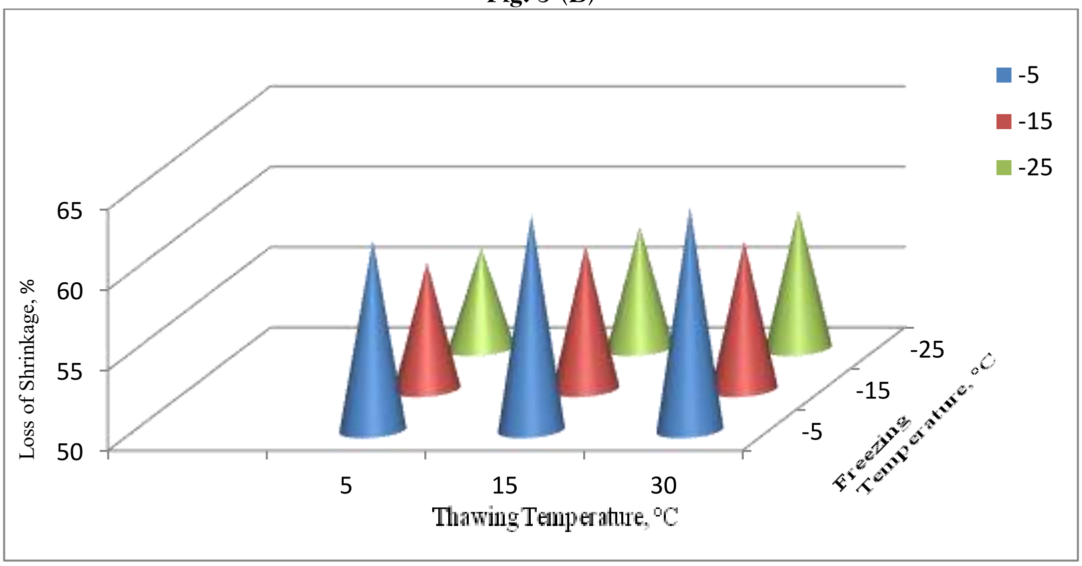

Fig. 3 (C)

Fig. 3: Effect of freezing and thawing temperature on apparent density, loss of shrinkage and percentage of shrinkage ratio of osmo-convectively dehydrated carrot slices

L*, a* and b* colour value

Control sample had significantly higher L-value than all the samples with freeze-thaw treatments. From the Fig. 4 (A), it is also observed that there was increasing effect on L* value with increase in freezing as well as thawing temperature. Lowest L* value was obtained for sample frozen as -25° C and thawed at 5° C temperature while higher value was recorded for -5° C freezing and 30° C thawing temperature. Lower L* values of pretreated osmo-dehydrated apple slices might be due to enzymatic or non- enzymatic browning before the osmotic dehydration process. Enzymatic browning in fruits and vegetables was a result of oxidation and polymerization of phenolic compounds by polyphenoloxidase (PPO) into quinines which further lead to dark pigments [18]. Overall higher L* value and lower a* and b* value were observed in control sample. This was in agreement with the results of higher a* and b* value for carrot snacks and apple slices with freezing pre-treatment respectively than unfrozen sample [21, 18].

There was a general decreasing trend in colour value a* whereas increase in b* values was noted increase in freezing and thawing temperature (Fig. 4. B and C). However, 15 and 30° C thawing temperature showed non-significant differences for L* and b* value of final dehydrated carrot slices. Lower L* and higher a* and b* values were recorded for lower freezing temperature than higher. This result is in close accordance with observation for strawberry as a result of increased freezing and thawing temperature [10]. Similar trend in colour were also observed due to slow and fast freezing for dehydrated carrots and quick cooking carrot respectively [22, 27]. However significantly higher a* and b* values were recorded for carrot slices pretreated with -25° C freezing and 5° C thawing temperature. Hence, the more yellowness in pretreated slices may be associated with the loss of water, subjecting to concentrate carotenoid content in the cellular tissue. This was in agreement with the findings of water loss that could resulted in increased β- carotene and lycopene in cherry tomato [28].

Table 4 : Effect of freezing and thawing temperature on changes in colour of osmo-convectively dehydrated carrot slices

Treatment	Colour			Chroma, (ΔC)	Hue angle (ΔH)
	L*	a*	b*		
To	48.23	25.12	22.84	33.95	42.28
T_1	44.18	32.83	33.39	46.81	45.35
T_2	45.36	32.58	32.69	46.01	45.27
T_3	45.89	32.20	32.48	45.73	45.18
T_4	43.13	33.70	34.40	48.16	45.49
T_5	44.21	33.37	33.71	47.92	45.37
T_6	44.33	33.04	33.59	47.21	45.26
T_7	42.05	34.25	34.98	48.96	45.62
T_8	43.35	33.95	34.43	48.48	45.48
T_9	43.69	33.61	34.26	48.04	45.39
SE	**0.355**	**0.104**	**0.195**	**0.148**	**0.037**
CD	**1.065***	**0.308***	**0.582***	**0.450***	**0.107***

*-5 % level of significance

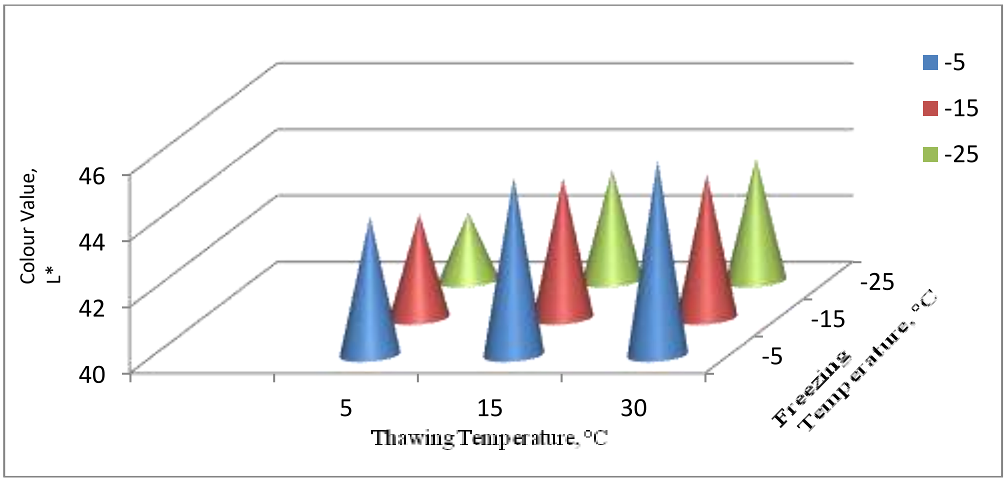

Fig. 4 (A)

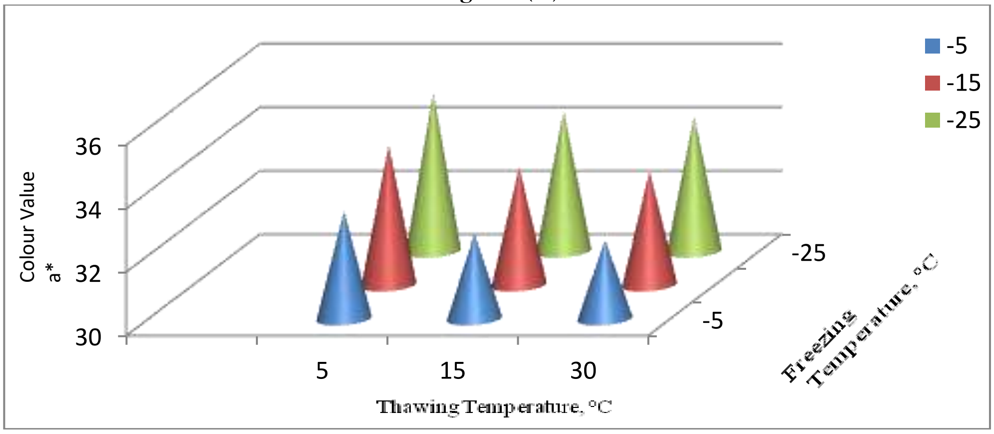

Fig. 4 (B)

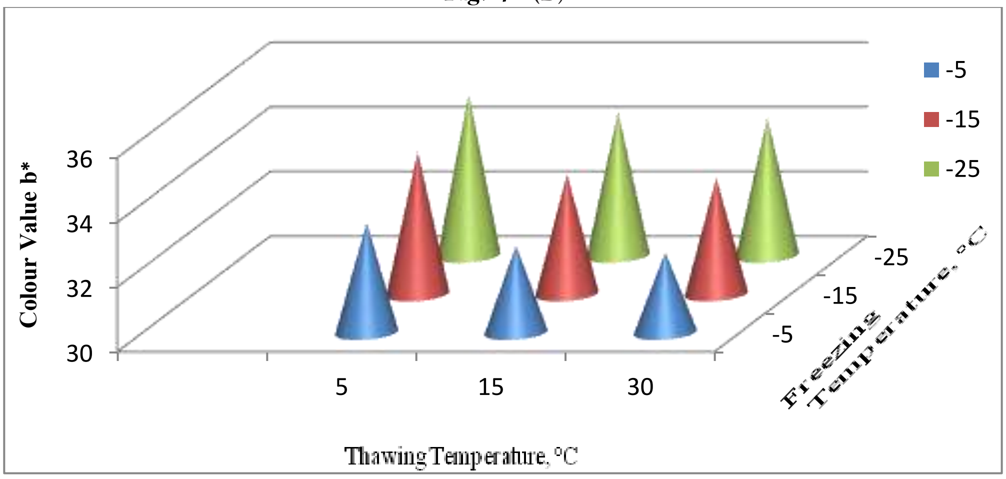

Fig. 4 (C)

Fig. 4: Effect of freezing and thawing temperature on colour values L*, a*and b*of osmo-convectively dehydrated carrot slices

Hue angle and chroma

Hue angle represents the spatial (position, area and size) distribution of colour than direct values of tri-stimulus measurements [29]. Smaller chroma value indicates greyness where as higher value indicates more vivid nature (deep intensity) of colour. Significant difference was found in hue angle and chroma values of unfrozen (control) and freeze-thawed carrot slices at 5 % level of significance. It was found (Table 4) that, hue angle and chroma values of osmo-convectively dried carrot slices varied from 42.28 to 45.62 and from 33.95 to 48.96, respectively.

Smallest hue angle (33.95) and chroma (42.28) were obtained for un-frozen sample, instead higher values were recorded for lower freezing (-25° C) and thawing temperature (5°C) respectively. Similar trend in hue angle and chroma of dehydrated carrots were observed for slow and fast freezing [22]. Lower hue angle and chroma was observed for higher freezing and thawing temperature than lower. These results are in close accordance for strawberry as result of increase in freezing and thawing temperature [10].

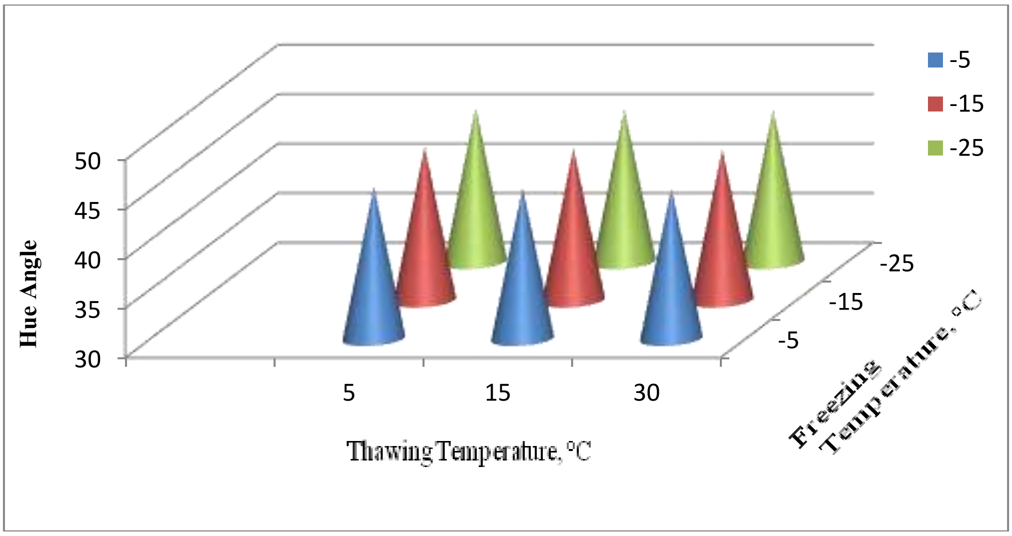

Fig. 5 (A)

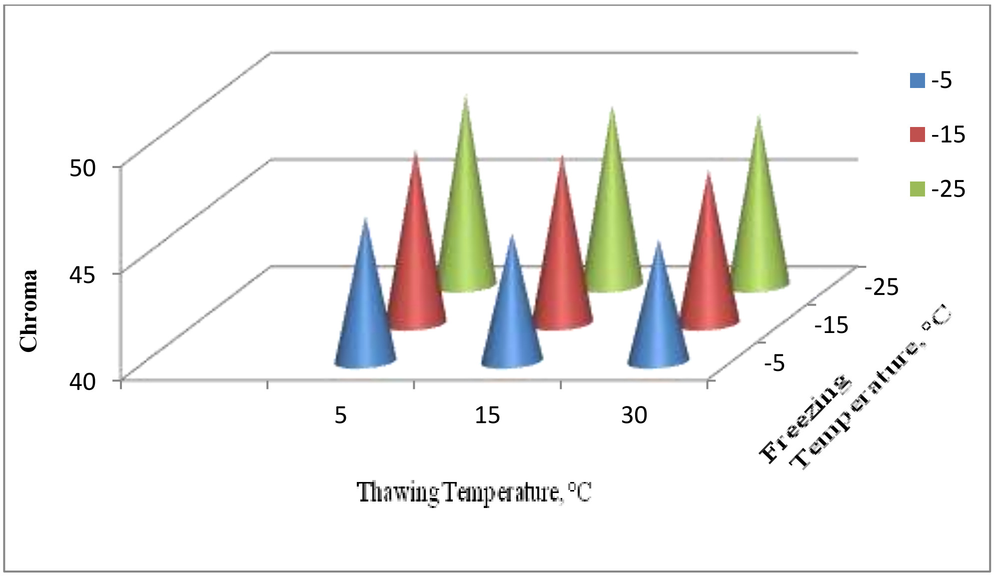

Fig. 5 (B)

Fig. 5 : Effect of freezing and thawing temperature on hue angle, and chroma of osmo-convectively dehydrated carrot slices

Sensory evaluation

Data presented in the Table 5 revealed that osmo-convectively dried carrot slices without freeze-thaw treatment obtained least score for various sensory parameters among pre-treated sample. Flaour of control sample was acceptable, but colour, appearance, taste and texture were not liked by judges. Osmo-convectively dried carrot slices pre-treated with -25° C freezing and 5° C thawing temperature scored highest value for colour and appearance whereas lowest score was obtained for carrot slices pre-treated with -5° C freezing and 30° C thawing temperature. Taste and texture of frozen and thawed sample at lower temperature obtained good score than higher freezing and thawing temperature. It might be due to higher sugar gain during osmosis of carrot slices frozen and thawed at lower temperature as compared to higher temperature. Slices prepared with -25° C freezing and 5° C thawing temperature obtained highest sensory scores for overall acceptability. An attractive color, good texture, a pleasant taste and good aroma was reported for the osmo- dehydrated pomegranate seed for lower freezing and thawing temperature [30].

Table 5: Effect of freezing and thawing temperature of slice on sensory parameters of osmo-convectively dehydrated carrot slices

Treatment	Color and Appearance	Texture	Flavor	Taste	Overall acceptability
To	6.5	6.4	8.0	6.5	6.4
T_1	7.9	7.7	8.3	8.2	7.7
T_2	7.4	7.4	8.1	8.0	7.5
T_3	7.3	7.3	8.0	7.8	7.3
T_4	8.2	8.2	8.4	8.3	8.2
T_5	7.9	8.0	8.2	8.2	8.0
T_6	7.8	7.9	8.0	8.1	7.8
T_7	8.8	8.9	8.8	8.8	8.9
T_8	8.2	8.1	8.6	8.5	8.2
T_9	8.0	8.0	8.5	8.3	8.0
SE	**0.034**	**0.061**	**0.036**	**0.056**	**0.064**
CD	**0.102***	**0.182***	**0.108***	**0. 119***	**0.191***

*- 5% level of significance

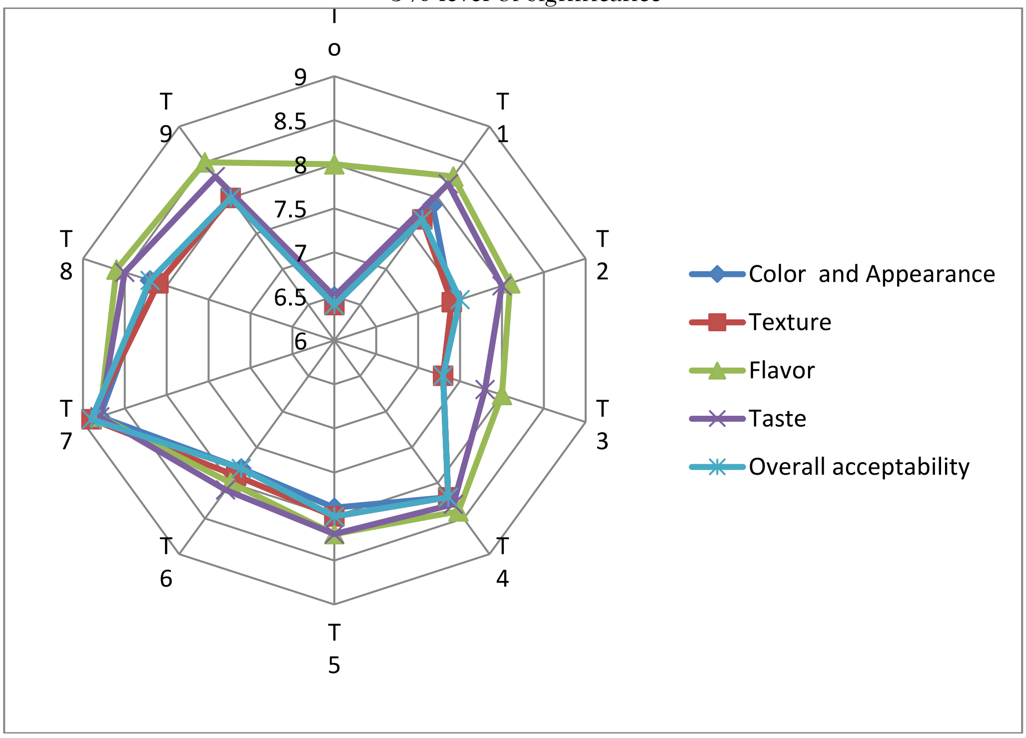

Fig. 6: Effect of freezing and thawing temperature on sensory parameters of osmo-convectively dehydrated carrot slices

Conclusion

Freeze-thaw pre-treatment significantly enhanced the mass transfer parameters during osmotic dehydration of carrot slices. Osmo-convectively dehydrated carrot slices prepared by using -25° C freezing and 5° C thawing temperature resulted in higher retention of hardness (texture), lower loss of shrinkage (%) and also recorded highest sensory acceptance.

References:

1- USDA. (2014). National Nutrient Database Composition of Foods Raw, Processed, Prepared. Http://Www.Nal.Usda.Gov/Fnic/Foodcomp/Search/.
2- Medina M. V, Sobra P.J L. do A & Hubinger M.D. (2002). Osmotic dehydration of tilapia fillets in limited volume of ternary solutions. *Chemical Engineering Journal* 86, 199-205.
3- Shi, J. and J. S. Xue. (2009). Application and development of osmotic dehydration technology in food processing. In Ratti, C. (Ed). *Advances in food dehydration.* CRC Press. USA.
4- Rastogi, N.K., Raghavarao K.S.M.S., Niranjan K. and D. Knorr. (2002). Recent developments in osmotic dehydration: methods to enhance mass transfer. *Trends In Food Science and Technology*, 13:48–59.
5- Falade Kolawole O. and Temilade A. Adelakun. (2007). Effect of pre-freezing and solutes on mass transfer during osmotic dehydration and colour of oven-dried african star apple during storage. *International Journal of Food Science and Technology,* 42: 394–402
6- Bachir Brahim, Souhail Besbes, Hamadi Attia and Christophe Blecker. (2011). Osmotic dehydration of pomegranate seeds (*punica granatum* l.): effect of freezing pre-treatment, *Journal of Food Process Engineering*, Periodicals, Inc., DOI: 10.1111/J.1745-4530.2010.00591.X
7- Kowalska Hanna, Andrzej Lenart and Dominika Leszczyk. (2008) The effect of blanching and freezing on osmotic dehydration of pumpkin. *Journal of Food Engineering,* 86: 30–38.
8- Paulina Nowicka, Aneta Wojdylo, Krzysztof Lech and Adam Figiel. (2015). Influence of osmo-dehydration pretreatment and combined drying method on the bioactive potential of sour cherry fruits, *Food Bioprocess Technol*, 8:824–836.
9- Konopacka D., Jesionkowska, K., Klewicki R. and C. Bonazzi. (2009). The effect of different osmotic agents on the sensory perception of osmo-treated dried fruit *Journal of Horticultural Science and Biotechnology,* Special Issue: 80–84.
10- Holzwarth Melanie, Sabine Korhummel, Reinhold Carle and Dietmar R. Kammerer. (2012). Evaluation of the effects of different freezing and thawing methods on color, polyphenol and ascorbic acid retention in strawberries (*fragaria × ananassa* duch.), *Food Research International*, 48: 242-248.
11- Singh Bahadur, Parmjit S. Panesar, A. K. Gupta and John F. Kennedy. (2007) Optimization of osmotic dehydration of carrot cubes in sucrose-salt solutions using Response Surface Methodology. *Eur Food Res Technol,* 225:157–165. Doi 10.1007/S00217-006-0395-9
12- Singh Bahadur, Parmjit Panesar, Vikas Nanda and J.F. Kennedy. (2010). Optimisation of osmotic dehydration process of carrot cubes in mixtures of sucrose and sodium chloride solutions. *Food Chemistry,* 123: 590–600.
13- El-Aouar A. A., P. M. Azoubel, J. L. Barbosa, and F. E. X. Murr,2006, Influence of the osmotic agent on the osmotic dehydration of papaya (Carica papaya L.), *J. Food Eng.*, 2006, doi: 10.1016/j.jfoodeng.2005.04.016.
14- Lazou Ae, Giannakourou Mg, Latha Ti and Es. Lazos. (2016). Kinetic study of the osmotic pretreatment and quality evaluation of traditional greek candied pumpkin. *Gavin J Food Nutrit Sci*, 28-36
15- Wang Hai-ou, Qing-quan Fu, Shou-jiang Chen,Zhi-chao Hu and Huan-xiong Xie, (2018). Effect of hot-water blanching pretreatment on drying characteristics and product qualities for the novel integrated freeze-drying of apple slices.*Journal of Food Quality*,1347513:12. DOIi.org/10.1155/2018/1347513
16- Farzaneh P., Fatemian H., E. Hosseini, Gh. H. Asadi and F. Darvish. (2011). A comparative study on drying and coating of osmotic treated apple rings. *International Journal of Agricultural Science and Research*, 2(2 -3).
17- Ruiz-Cabrera, M.A., Flores-Gomez, Gonzalez-Garcia, R.' Grajales-Lagunes, A., Moscosa-Santillan, M. and M. Abud-Archila. (2008) Water diffusivity and quality attributes of fresh and partially osmo-dehydrated cactus pear (opuntia ficus indica) subjected to air dehydration. *International Journal of Food Properties* **,** *11* (4): 887–900.
18- Taiwo Kehinde A, Alexander Angersbach, Beatrice I. O. Ade-Omowaye and Dietrich Knorr. (2001). Effects of pretreatments on the diffusion kinetics and some quality parameters of osmotically dehydrated apple slices. *J. Agric. Food Chem.*, *49,* 2804-2811
19- .Ade-Omowaye, B. I. O., Taiwo, K. A., Eshtiaghi, N. M., Angersbach, A. and D. Knorr. (2003). Comparative evaluation of the effects of pulsed electric field and freezing on cell membrane permeabilisation and mass transfer during dehydration of red bell peppers. *Innovative Food Science and Emerging Technologies*, 4:177–188.
20- Cheftel J. C., J. Lévy and E. Dumay. (2000). Pressure-assisted freezing and thawing: principles and potential applications. *Food Reviews International*, 16(4):453-483.
21- Albertos I., Martin-Diana, A.B., Sanz M.A., Barat J.M., Diez A.M., Jaime I. and D. Rico. (2016). Effect of high pressure processing or freezing technologies as pretreatment in vacuum fried carrot snacks. *Innovative Food Science And Emerging Technologies*, 33:115-122.
22- Gill Gurunaz Singh, Satish Gupta, T. C. Mittal and S. R. Sharm. (2014). Effect of freezing and blanching on quality traits of carrot, Journal of Research, Punjab Arricultral University, Sep-Dec. 2014, 51(3 and 4) pp: 286-290

23- Zhiqiang Xu, Yunhan Guo, Shenghua Ding, Kejing An and Zhengfu Wang. (2014). Freezing by immersion in liquid co_2 at variable pressure response surface analysis of the application to carrot slices freezing. *Innovative Food Science and Emerging Technologies*, 22:167–174.

24- Buggenhout S. Van, Sila, D.N., Duvetter T., Van Loey A. and M. Hendrickx. (2009). Pectins in Processed Fruits and Vegetables: Part III—Texture Engineering , Institute of Food Technologists, CRFSFS: Comprehensive Reviews in Food Science and Food Safety

25- Rahman, M. S., Al-Amri, O. S. and I. M. Al-Bulushi. (2002). Pores and physico-chemical characteristics of dried tuna produced by different methods of drying. *Journal of Food Engineering*, *53*(4), 301-313. https://doi.org/10.1016/S0260-8774(01)00169-8.

26- Charoenrein, S., and K. Owcharoen. (2016). Effect of freezing rates and freeze-thaw cycles on the texture, microstructure and pectic substances of mango. *International Food Research Journal*, 23(2), 613–620

27- Yadav, YS and K. Prasad. (2017) Development and characterization of shelf stable quick cooking carrot, *International Food Research Journal,* 24 (1): 465

28- Usamas Jariyawaranugoon. (2015). Effect of freezing on quality of osmotically dehydrated banana slices, *Advance Journal of Food Science and Technology*, 9(2): 98-105, 015 Doi: 10.19026/Ajfst.9.1941

29- Patras, A., Tiwari B.K. and P. Brunton. (2011). Influence of blanching and low temperature preservation strategies on antioxidant activity and phytochemical content of carrots, green beans and broccoli. *LWT - Food Science and Technology*, 44: 299-306.

30- Ibrahim Doymaz, (2015) Infrared drying kinetics and quality characteristics of carrot slices, *Journal of Food Processing and Preservation*, 39:2738–2745. DOI: 10.1111/jfpp.12524