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Impact of freezing methods on the physicochemical and sensory qualities of frozen carrot (*Daucus carota*) (Cape Market variety) dices

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Abstract Carrots (*Daucus carota*) are root vegetables that contain carotenoids, flavonoids, polyacetylenes, vitamins, and minerals. They are high in antioxidants, anticarcinogens, and immune enhancers making them excellent for the eyes. Carrots suffer from significant postharvest losses in Sri Lanka due to their perishable nature, as well as rejections due to their odd morphologies. Even though demand for carrot is high all around the country, losses are unavoidable. Freezing techniques play a vital role in maintaining freshness and avoiding deterioration simultaneously. The goal of the present study was to find the best freezing method among blast freezing (-30 °C) and conventional (-18 °C) freezing circumstances for a superior quality of frozen carrot dice. Blanched (90 °C for 3min) carrot dice (Cape market variety) were frozen and thawed, then physicochemical parameters like drip loss (%), pH and colour, and other aspects including length ratio, hardness and cutting shearing strength and sensory parameters like colour, odour, texture and overall quality changes during freezing were analyzed. The blast frozen-thawed carrot dices showed the best quality of fresh colour, 8.50 ± 2.83 of colour change, 5.573 ± 0.555 % of drip loss, 0.0333 ± 0.007 length ratio, 21.53 N ± 3.78 hardness, 0.1366 J ± 0.0361 cutting and shearing strength, and 5.6867 ± 0.01 pH than conventional frozen-thawed dices. Mann Whitney U test resulted that blast frozen carrot dices had significantly ($p<0.05$) higher consumer preference than conventionally treated samples during the sensory analysis.

Keywords: Blast freezing, carrot deterioration, conventional freezing, frozen carrots, quality of carrots.

1 Introduction

Fresh carrots are one of the preferred vegetables by people due to their nutritional value and the favorable crispy mouth feel. According to Haq and Prasad (2015) studies, carrots contain 84 - 95% moisture, 0.6 - 2% protein, 0.2 - 0.7 fat%, 9.58 - 10.6%

carbohydrates, 5.4 - 7.5% sugars and 0.6 - 2.9% fibers. They don't provide much in the way of calories, but they do provide nourishment in the form of phytochemicals like carotenoids, anthocyanins, and other phenolic compounds (Arscott and Tanumihardjo 2010).

Raw carrots have a high preference as a domestic consumer product as well as an export item in Sri Lanka too. According to Sri Lankan statistical studies, the average annual yield (tonnes/ha) of carrots in 2017 is 19.42. Department of Census & Statistics and External trade statistics, Sri Lanka Customs reports that 14 tonnes of carrots were imported to Sri Lanka in 2017 (Anon 2018). As a result, Sri Lankan carrots play a significant role in the local and international markets. 'Cape market' and 'Top weight' are the two most popular carrot cultivars in Sri Lanka.

Post-harvest losses in fruits and vegetables are major concerns in the Sri Lankan food sector, with 30-40 % of vegetables end up as waste (Rajapaksha *et al*. 2021). Whole carrots have a lower marketable grade and less demand as a result of forking and physical quality deterioration. Therefore, farmers and collectors are requested to give suggestions or guidance to the Food Research unit, Gannoruwa, Sri Lanka to increase the shelflife and improve the value addition of carrots. The most serious issue with commercial carrot production in Sri Lanka is high postharvest losses owing to fungus and bacteria-causing soft rot (Naligama and Halmillawewa 2022). *Sclerotinia* rot and bacterial soft rot are the main post-harvest diseases in carrots that cause massive product deterioration in Sri Lanka (Galati *et al*. 2005, Naligama and Halmillawewa 2022). Therefore, there is a need for the preservation of vegetables without a loss in their fresh quality.

The frozen food sector has become dynamic and popular in the global market currently. Freezing is one of the best methods to preserve the same freshness in vegetables without reducing quality. High temperature treatments like thermal drying cause heat damage to the texture of the vegetable, making the product low in value (Deng *et al*. 2019). It also negatively affect the sensory parameters of vegetables (Seljåsen *et al*. 2013). In contrast, low temperature carrot preservation techniques are more beneficial to keep the fresh characteristics and to enhance the beta carotene content (from 8% to 23% from fresh) (Berger *et al*. 2008).

Changes in the consumption patterns of consumers including 'ready to eat' or 'easy to prepare meals' and the replacement of food like vegetable alternatives instead of those of animal origin have motivated a marked increase in demand for frozen vegetables in the food industry. Significant growth in women's employment rate and busy lifestyles may also increase the demand for processed foods like frozen fruits and vegetables, because cleaning and cooking/ processing have become difficult and time-consuming to them (Etilé and Plessz 2018).

Low-temperature preservation, which can be a component of organic product lines without using preservative chemicals inhibits microbial growth and development causing degradation. It will also assist in the preparation of ready-to-eat carrots or by-products as required especially by the working people. The goal of this study is to compare the physicochemical and organoleptic characteristics of carrots between conventional freezing (-18 °C) and blast freezing (-30 °C) in order to determine the optimal cold preservation technique. Cape market carrots with a big orange core and a dark orange tuber (25-30cm) that were widely cultivated in Sri Lanka were chosen for this study.

2 Material and Methods

2.1 Location and materials

The research study was conducted at Food Research Unit, Gannoruwa, Peradeniya, Sri Lanka and Department of Food Science and Technology, Faculty of Agriculture, University of Peradeniya, Sri Lanka from December 2020 to June 2021.

Fresh cape market species carrots (*Daucus carota* subsp. *sativus*) were purchased directly from a local market in Gannoruwa, Sri Lanka. To ensure the homogeneity in samples, fresh carrots were selected from one farmer, same maturity stage, i.e., visually similar colour and size.

2.2 Methodology

Sample Preparation

Two minutes of washing with chlorinated water, and manual knife cutting of carrots into dice (2×2 cm^2) were practiced to increase the surface area.

Blanching pretreatment and freezing

According to the trial results, carrot dice were blanched in distilled water at 90 °C for 3 minutes. From time to time, the temperature of the dices was measured by a thermometer (Temperature & Humidity meter, Model DTM-320, TECPEL 320 series, Taiwan). Soon after blanching, the dices were cooled with distilled water at room temperature.

The remaining surface water on the pretreated vegetable samples was removed by muslin cloth. After that, they were packaged into labeled polypropylene material and sealed airtight by the sealer (300 FE, Sevana, India).

There were two types of freezing methods (Treatments) that were practiced.

1. Conventional freezing at -18 °C was carried out in a conventional deep freezer (RS55K5010S9/TL, SAMSUNG, Digital Inverter Technology Co., Ltd, Newdelhi, India.)
2. Air blast freezing at -30 °C (velocity 3m/sec) was performed in an air blast freezer (Bitzer 75hP, BITZER Co., Ltd., Bangkok, Thailand).

During both freezing processes, K type thermocouples (RS-232 Test Link, TECPEL) were used. Thermocouples were inserted to measure the core temperature of the samples, and to record temperature every 30 sec since the core temperature (from 28 °C) reached -18 °C.

Physicochemical Analysis

Colourimeter (CS-10, CHN Spec, Zhejiang, China) was used to measure the surface colour of carrot dice. The colourimeter was calibrated against references and the L, a and b value measurements were taken. To evaluate the colour change of samples after the blast and conventional freezing treatments from fresh samples were calculated by colour difference (ΔE) values. The ΔE values were measured using the following formula,

$$\Delta \mathrm{E} = \sqrt{((\Delta \mathrm{L})^2 + (\Delta \mathrm{a})^2 + (\Delta \mathrm{b})^2)}$$

where, $\Delta L = L - L_o$, $\Delta a = a - a_o$, $\Delta b = b - b_o$, L_o, a_o, b_o and L, a, b are the colour values of fresh and frozen vegetables respectively (Rajkumar *et al*. 2017).

For drip loss% determination, first, the weight before thawing of carrot dice was measured by analytical balance (AS 310.R2, RADWAG, Torunska, Poland), and then, those samples were thawed under ambient conditions for 2h. The liquid portion that remained in the package was removed and the pulp weight was measured after thawing. According to the following formula drip loss of the carrots was measured (Phothiset and Charoenrein 2014).

$$Drip\ loss\ \% = \frac{Weight\ before\ thawing(g) - Weight\ after\ thawing(g)}{Weight\ before\ thawing(g)} \times 100\%$$

Length ratio was measured by Vernier caliper (NIS, made in Poland) for carrot dices (Rajkumar *et al*. 2017). The formula used was,

$$Ratio\ of\ Length = \frac{Treated\ dice\ length(cm) - Fresh\ dice\ length(cm)}{Fresh\ dice\ length(cm)}$$

Hardness and cutting & shearing strength of carrot dices were measured by texture analyzer (SHIMADZU compact tabletop testing machine EZTest, EZ-X Series, Kyoto, Japan). The determination was done using a single-point aluminum probe whereas the test speed was 1m/s. Cuts were made in the middle of dices to get homogenous measurements in triplicate samples for each treatment. The unit for hardness measurements was Newton (N) and the unit for cutting & shearing strength was Joule (J).

According to AOAC (981.12) methods, the pH of carrots was measured at 25 °C by a digital pH meter (EUTECH PC 450, Thermo scientific pH meter, Waltam, USA).

Sensory Analysis

Five-point hedonic tests were used with 30 semi trained panelists for the sensory evaluation. Frozen- thawed (into distilled water for 2 hours at room temperature 28 °C) cape market variety carrot dices were evaluated for their colour, odour, texture and overall acceptability sensory parameters. The sensory analysis was conducted at the sensory lab, Department of Food Science and Technology, Faculty of Agriculture, University of Peradeniya.

2.3 Statistical analysis

The data were reported as mean standard deviation (SD) after three replicate studies (n=3). Drip loss (%), shrinkage ratio and ΔE value of colour were analyzed as Mann Whitney U test using Minitab 14 software and other physiochemical parameters were analyzed in CRD design using SAS 9.0 at the 5% of the significance level. The sensory parameters were tested in the Mann Whitney U test via SPSS 16 software.

3 Results and Discussion

3.1 Physicochemical analysis of frozen carrot dices

Colour

Consumers who link colour with quality use it as the primary factor for accepting or rejecting food goods. The vibrant colours of fruits and vegetables stimulate appetite and digestion while also increasing food pleasure (Wadhera and Capaldi-Phillips 2014). The most prevalent category of carotene in carrots as colour pigments are beta carotenes, which are antioxidants (Dai and Row 2019), while orange carrots are one of the best sources of pro-vitamin A carotenoids in the diet (Eggersdorfer and Wyss 2018).

The colour of frozen carrot dice both under blast and conventional freezing did not show any significant ($p<0.05$) differences in Δa and Δb values (Table 1) with fresh samples. But the ΔL (Figure 2) values showed significant ($p<0.05$) differences in both freezing treatments. The median of blast freezing treated ΔE values (8.5) are less than the median of conventional freezing treated samples (10.64). It indicates that the magnitude of colour difference is higher in conventional freezing than blast freezing. BFT carrots kept their red, yellow, and vivid colours longer (Table 1). Oxidation of carotenoids is considered to be the major cause for the colour variations in carrots (Rajkumar *et al*. 2017). Furthermore, enzymatic reactions and browning reactions which additionally contribute to the brown, gray and black colour of the fruits and vegetables may be higher in conventionally treated samples (Barrett *et al*. 2010).

Table 1: Colour variables of the blast and conventional freezing treated carrot dices.

Colour parameter	Treatment type		
	Fresh	BFT (-30°C)	CFT (-18°C)
L*	56.330 ± 1.602	49.94 ± 1.79 [a]	47.71 ± 2.73 [a]
a*	21.187 ± 0.805	17.14 ± 1.80	17.02 ± 4.10
b*	40.197 ± 1.093	37.68 ± 3.84	35.26 ± 1.062
ΔE		8.50 ± 2.83	10.64 ± 4.11

[a] Means ± SD values are significantly different from fresh samples.
BFT=Blast freezing treated, and CFT=Conventional freezing treated.

Drip loss%

According to the statistical analysis, median values of drip loss in blast frozen samples are less than the conventional frozen samples ($p<0.05$). The drip loss (%) at blast and conventionally frozen carrot dices were as 5.557 ± 0.555 % and 5.573 ± 1.132 % respectively. The higher drip loss % in conventional freezing is probably due to the rupture of the cell wall and cell membrane by the large size of ice crystal formation (Xu *et al*. 2017).

After freezing the fruits and vegetables need to be thawed before cooking and consumption. During the freezing process of water, the crystallization rate and the location of crystals form depend on the rate of heat removal, tissue structure and the rate of diffusion of water from the solution to the surface of the ice crystals. At low freezing rates, few crystallization nuclei form. Through the cell membrane, the cell loses water by extracellular diffusion causing solute to concentrate and form crystallization inside the cells. At the same time, the extracellular crystals cause progressive separation of cells due to their large size. But in rapid freezing, it is a contrast (Creed 2005). During freezing and thawing, there will be temperature fluctuations. This may be extremely damaging to the microstructure of the frozen vegetables (Phothiset and Charoenrein 2014). Due to that, the cell sap gets leached out from the cell, which is called drip loss of frozen foods.

Length ratio

The observed length ratio of blast frozen and conventional frozen dices were 0.0333 ± 0.007 and 0.045 ± 0.005 respectively. The length ratio in blast frozen samples did not show any significant ($p<0.05$) differences, which means that there are no considerable changes in the length during blast freezing compared to fresh carrot dices. Conventional freezing treated carrot dices had shown significant ($p<0.05$) differences. The statistical analysis indicated a higher length change (0.09 cm) at slow freezing conditions. Volume changes of water to ice formation may result in the increase of length in frozen vegetables.

Hardness and Cutting & shearing strength

Both of the freezing methods showed significant ($p<0.05$) differences in hardness and cutting & shearing strength concerning fresh carrot dices. When the means are compared (Table 2), the blast-freezing treated carrot samples have shown higher textural values than conventional freezing treated samples.

Table 2. Hardness, Cutting & shearing strength and pH of blast and conventional freezing treated carrot dices.

Parameter	Treatment		
	Fresh	BFT (-30°C)	CFT (-18°C)
Hardness (N)	50.82 ± 5.66	21.53 ± 3.78[a]	11.44 ± 1.90 [a]
Cutting & shearing strength (J)	0.2649 ± 0.0273	0.1366 ± 0.0361[a]	0.0733 ± 0.0206 [a]
pH	5.7500 ± 0.0436	5.6867 ± 0.0153	5.5833 ± 0.0764[a]

[a] Means ± SD values are significantly different from fresh samples.
BFT=Blast freezing treated, and CFT=Conventional freezing treated.

There is a correlation between freezing rate, ice crystal size and textural quality during different freezing procedures (Tan *et al*. 2021b). Vegetables suffer less damage because of small ice crystal formation during rapid freezing. But in slow freezing large ice crystals formed and damage is high caused by low quality (Li *et al*. 2018, Tan *et al*. 2021a). Neri (2014) described that destruction of the cytoplasmic structure, loss of turgor, weakness of cell wall and cell separation in carrot during freezing caused reduction of cutting & shearing strength and hardness values and also the temperature of freezing is a critical factor for cell damage in carrots. During blast freezing, low freezing temperature and fast rate of freezing (quick freezing) results in less cell damage in comparison to conventional freezing. Elastic strength can be reduced by the degradation of cell wall components of carrots (Xu and Li 2015).

pH

The pH of the blast freezing treated carrot dices did not show any significant ($p<0.05$) difference and conventional freezing treated samples showed significant ($p<0.05$) differences compared to fresh samples (Table 2). The BFT carrot dices did not show considerable changes in pH compared to fresh dices. The pH changes/reduces during the ice formation in vegetables, because of the super saturation of sodium and Calcium phosphates (Van Den Berg 1966, Gómez *et al*. 2001). Research have revealed that the initial pH drops due to the precipitation of alkaline phosphates of calcium, magnesium and sodium, whereas the final increase of pH is suggested as due to acid phosphates of potassium (potassium citrate) and sodium (Creed 2005).

3.2 Evaluation of the acceptability and compare the freezing treatments of frozen carrots

Some research reveals that many factors influence the consumers to buy/prefer fresh to frozen vegetables such as taste, texture quality perceptions and nutritional qualities (Pamela and Brenna 2016). According to the statistical analysis, preferences for the blast freezing and conventional freezing were significantly ($p<0.05$) differentiated concerning colour, odour, flavour and overall quality, while preferences for the two methods were not significantly ($p<0.05$) differentiated with respect to the texture. Preference for blast freezing was significantly ($p<0.05$) higher than the conventional method for colour, odour and overall quality (Figure 1). Even though the nutritional content of blast and conventional frozen carrot dices was not informed to the panelists, the preference for the change towards blast frozen carrot dices depends on physical parameters too.

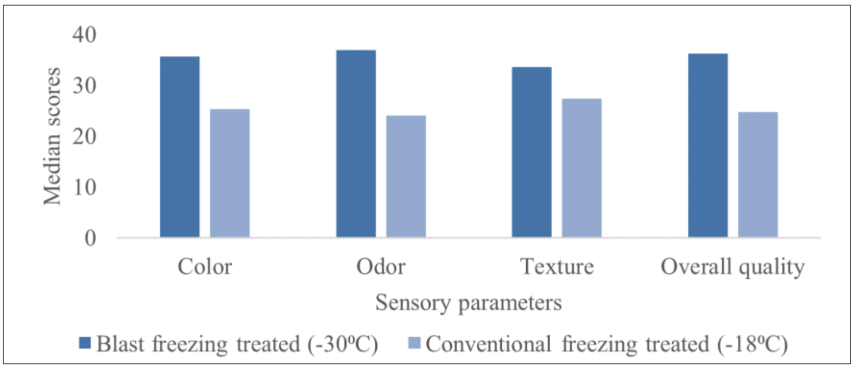

Fig 1. Median scores of consumer preference for blast and conventional frozen carrot dices.

4 Conclusions

In comparison to conventional freezing (-18 °C), blast freezing (-30 °C) preserves ($p<0.05$) physicochemical parameters (color, drip loss%, length ratio, hardness, cutting & shearing strength and pH) of carrots. The small size of ice crystal formation and fast freezing rate result in preserving the freshness of the carrots-cape market variety. Sensory analysis showed higher consumer preference ($p<0.05$) in terms of colour, odour and overall quality for blast frozen samples which indicates that the blast frozen samples will be of higher market demand. According to the vegetables, certain chemical and physical parameters change concerning freezing conditions. Therefore, Sri Lanka's frozen food industry can focus on freezing carrots using the blast freezing technique in the future.

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