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Effect of freezing systems and storage temperatures on overall quality of perishable food commodities

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Abstract
Freezing is a very well-established food preservation process that produces high quality nutritious foods with a long storage life. However, freezing isn't appropriate for all types of the food materials, as it may cause physical, bio-chemical and sensory changes in some foods that are perceived as reducing the quality of the final product especially after thawing. The food industry employs both chilling and freezing processes where the food is cooled from ambient to temperatures above 0 °C in the former and between −18 °C and −35 °C in the latter to slow the physical, microbiological and chemical activities that cause deterioration in foods. This paper provides a brief review of freezing systems used in food processing industries for preservation of perishable food commodities. There are different types of freezers used in food industries for different commodities like air blast freezer, plate freezer, contact freezer, immersion freezer, cryogenic freezer, individual quick freezer etc. Selection of freezer and refrigerant depends on the type, moisture content, nature and pretreatments given to particular food commodity before freezing. Freezing may also causes damage to cells of fruit and vegetable by ice crystal growth. However, freezing retains most of the pigments, aroma, flavors, characteristic taste and other nutritional components in most of the perishable food commodities.

Keywords: Refrigeration, freezer burn, fruits and vegetable, IQF, air blast freezing

1. Introduction

Freezing is one among the foremost widely used method because it can stop or inhibit microbiological growth (Archer, 2004) [6], and helps to preserve original sensory and nutritional qualities (Degner *et al*., 2013) [15]. Yet, the textural quality of frozen food is extremely associated to freezing and thawing procedures. Upon freezing food products, two fundamental steps are normally required to produce products with high quality, those are quick freezing and storing at a constant sub-freezing temperature (Petzold *et al.*, 2009) [52]. In food factories, the ready-to-eat meals are normally quick-frozen to a temperature near -15 to -20 ºC (Evan, 2008) [21] using cryogenic technique. This method controls ice nucleation in the way that water can transform into small ice crystals (Kennedy, 2000) [37]. Apart from freezing technique, ice formation, i.e. ice nucleation and growth, is additionally effected by characteristics of food being frozen like mass and component (Degner *et al.*, 2013) [15].In freezing operation the temperature of the product usually reducing to -18 ºC or less. (Fennema *et al.*, 1975) [24]. The low temperature inhibits the expansion of microorganisms and delay chemical changes that can affect the overall quality or cause food to spoil (George, 1993) [30].

Low temperature preservation of perishable food products such as fruits and vegetables is a crucial and interesting application of heat transfer and thermodynamics. Refrigeration delays the chemical and biological processes in foods and also the accompanying degradation and different quality losses. The storage life of fresh perishable fruits and vegetables can be extended by several days by cooling (1 and 4 ºC) and several weeks or months by freezing (-18 and -35 ºC). There are many considerations in the design and selection of proper refrigeration and heat transfer mechanisms, For example, fruits and vegetables continue to respire and generate heat during storage, most of the fruits and vegetables freeze over a range of temperatures instead of a single temperature, the quality of frozen products is greatly affected by the rate of freezing, the velocity of refrigerated air affects the rate of moisture loss from the products addition to the rate of heat transfer (Fridlind *et al.*, 2007) [27].

Refrigeration is defined as the production of temperature lower than those of the surrounding and maintains the lower temperature within the boundary of a given space. The effect has been accomplished by non-cyclic processes such as the melting of ice or sublimation of solid carbon

dioxide. However, refrigeration effect is usually produced by transferring heat from a low temperature source to a high temperature source by spending mechanical work. To produce this effect requires certain machinery.

Table 1: Freezing point of different perishable food commodities with moisture content

Food	Water content (%)	Freezing point ºC
Vegetables	78-92	-0.8 to -2.8
Fruits	87-95	-0.9 to -2.7
Meat	55-70	-1.7 to -2.2
Fish	65-81	-0.6 to -2.0
Milk	87	-0.5
Egg	74	-0.5

***Source*:** Fellows, 1990 [22]

Hence; the method is called mechanical refrigeration. The working media of such machines are called refrigerants (Anon., 2018a) [5]. Different types of refrigerant gases include Cholorofluro carbon (CFC), Hydro chlorofluorocarbons (HCFC), Hydro fluorocarbon (HFC) and Perflurocarbon (PFC). Some toxic gases such as ammonia (NH_3), Methyl chloride (CH_3Cl), Sulfur dioxide (SO_2) and liquid refrigerants like propylene glycol, brine, glycerol or calcium chloride solution are also used for freezing (Noyes, 1942) [51].

Freezing is the process of food preservation that preserves the greatest quantity of nutrients. To preserve top nutritional quality in frozen fruits and vegetables, it's essential to pick out fresh, firm-ripe produce, blanch vegetables as directed, store the frozen product at 0°F and use within suggested storage times (George, 1993) [30].

2. Methods of Freezing

The process of freezing could be a crucial consideration within the freezing of perishable foods like fruits and vegetables. Common freezing methods include air-blast freezing, where high-velocity air at about -30 ºC is blown over the food products, contact freezing, where packaged or unpackaged food is placed on or between cold metal plates and cooled by conduction, immersion freezing, where food is immersed in low temperature brine, cryogenic freezing, where food is placed in a medium cooled by a cryogenic fluid such as liquid nitrogen or liquid or solid carbon dioxide and the combination of the above methods (Hung *et al.*, 1983) [35].

The killing of bacteria is largest in the range -4 °C to -10 °C due to cold-shock, where their metabolism is disturbed, even stopped. When the freezing rate is slow, the bacteria have time to adapt to the new conditions, hence food must be frozen quickly. There are various methods available for food freezing, these include: air-blast freezers (batch and continuous), fluidized bed freezers, impingement freezers, liquid immersion freezers, plate freezers, liquid nitrogen freezers and carbon dioxide freezers. Versatility is the significant application of the air blast freezer. Since air is a low viscosity fluid it has the ability to easily follow around irregular surface geometries, thus providing a more uniform freezing rate over the whole product. Other freezing methods such as plate freezing (contact freezing) offer faster cooling times, but can only be used with products of a suitable geometry (Hessami, 2004) [33].

3. Freezers used for Perishable Food Commodities

3.1 Air blast freezers

Air blast freezers are used extensively throughout the world to freeze various food commodities from carcasses to packaged goods. They are popular within the freezing industry due to their versatility to freeze items of any shape and size. Air blast freezers are used to freeze food commodities from a chilled temperature to their desired storage temperature (product dependent) with air temperatures between -35 °C and -45 °C with varies freezing time from 12 to 48 hours (Dempsey, 2010) [16]. Air blast freezing is the process that taking of a product at a temperature and freeze it quickly just in between 12 and 48 h, at its low storage temperature which varies from product to product (e.g. fish = -20 ºC, beef = -18 ºC). Slow freezing, due to more freezing time produces comparatively large ice crystals. Therefore, in quick freezing, due to formation of higher number of nucleation points, small ice crystals produces and maintain the overall quality of the perishable food products (Dempsey *et al.*, 2012) [17].

Boonsumrej *et al.*, (2007) studied the changes of quality of tiger shrimp which frozen by air blast freezing at -28 ºC and on different air velocity (4-8 m/s). Shrimps frozen at the air velocity of 6 m/s had the smallest (%) freezing loss and similar cutting force to the fresh products. Martins and Lopes (2007) [48] investigated the quality of frozen strawberries which were influenced by the super-cooling capacity throughout air blast freezing on operational variables, initial temperature, air temperature, air velocity and strawberry maximum diameter.

3.2 Plate freezers

Plate freezers are often arranged with the plates horizontal to create a series of shelves and, because of this horizontal arrangement, classified as horizontal plate freezers (HPF). Whereas, if the plates are attached at vertical plane and form a series of bins, are known as vertical plate freezers (VPF). In horizontal plate freezers, the product is packed into freezing trays before freezing. The trays may either be lined with polyethylene sheet prior to packing, or cartoons may be used. Depending on the product, the aluminum trays may divide into compartments to give uniform block sizes, the trays, which may also have closely fitting lids, are then placed on the freezer shelves. The hydraulic system positions the plates in close contact with the top and bottom of the trays to ensure maximum heat exchange. Trays and cartons should be filled to the top to ensure good contact with both plates. Whereas, in vertical plate freezer, a refrigerant runs through a variety of plates arranged vertically. direct contact method of freezing makes vertical plate freezer more suitable to quick freezing of perishable food products, which increases a major energy saving and lower freezing time (Heap, 1997) [32].

3.3 Contact freezer

Contact freezing is a combination of two steps, the first step is the requirement that a collision between a super cooled droplet and aerosol particles takes place and the second step is the initiation of ice formation. Air molecules at the warmer side have a higher kinetic energy and thus exert a net force on the particles towards the colder temperature (thermo phoresis). At the same time, a water vapor gradient (diffusion phoresis) is generated in the opposite direction, which moves the aerosol particles in the opposite direction as thermo phoresis. Electro-scavenging and the phoretic forces are relatively more important in the "Greenfield gap", i.e., at the transition regime between Brownian motion and inertial impaction (Moreno *et al.*, 2013) [49].

Contact freezing is one of four heterogeneous ice formation

mechanisms responsible for glaciation of such clouds, the other three being condensation, immersion, and deposition freezing. It occurs when an aerosol particle makes contact with a super cooled cloud droplet and causes its freezing (Vali, 1985) [64]. Contact freezing might eventually explain the discrepancy between the measured number of ice nuclei (IN) and observed number concentration of ice crystals in a cloud (Avramov *et al*., 2011; Fridlind *et al.*, 2007) [7, 27]. A number of researchers i.e. Durant *et al.*, 2005 [20]; Fornea *et al.*, 2009 [25]; Fukuta, 1975 [28] and Ladino, 2013 [38] consistently reported contact freezing taking place at temperatures that were a few degrees higher than the immersion freezing initiated by the same IN, no generally accepted explanation of this phenomenon exists up to this day. In particular, it is not known whether the enhancement is caused by some kind of pre-activation of the IN particle shortly before the contact with the super cooled droplet (Cooper, 1974) [13], or by the facilitation of ice nucleation in the surface layer of a water droplet (Djikaev *et al*., 2002) [18].

Vegetable pieces frozen in 23% Nacl (AF 23-O) aqueous solutions and given suitable post-freeze treatments reach solute levels ranging from as low as 0.48% Nacl for peas to 2.19% for diced carrots. Lowest salt levels are comparable to levels of salt in canned products and highest values are comparable to levels in remanufactured items such as soup. Solute reduction methods of blotting or washing in 11.5% Nacl produce comparable reductions of solute, and combined washing and blotting was more effective than either method alone. Vegetable pieces are often cooled and frozen to 2 ºF in aqueous refrigerant (Nacl) in 1.0 min or less. Estimated processing cost of AF frozen product is less than cost of air blast or fluidized bed frozen product (Robertson *et al*., 1976) [56].

3.4 Immersion freezer

For products where rapid freezing is appropriate, direct contact between a liquid refrigerant such as nitrogen or carbon dioxide may be used. The product is carried on a conveyor through a bath of liquid refrigerant to establish direct and intimate contact with the liquid refrigerant (Sinha, 2011) [60]. Immersion freezing also consists of directly contacting food with a chilled aqueous solution (<0 ºC). Binary brine solutions are generally used most often sodium chloride or calcium chloride (Robertson *et al*., 1976) [56]. Immersion chilling and freezing has been studied for whole or pieced foods, e.g.: carrots and peas, potatoes, fish and crabs, fruits, pork and poultry and packaged liquids, such as fruit juices (Cipoletti *et al*. 1977; Robertson *et al*., 1976; Noyes, 1942) [12, 56, 51]. Immersion freezing has been used extensively for on-board freezing of fish but its industrial use on other products has been limited. There is a two-fold advantage of immersion freezing over air blast freezing. Overall, energy consumption could be reduced by ≥25% with immersion freezing. It is one of the fastest freezing techniques, because heat transfer coefficient is at least 10-fold higher in the liquid phase than in air (Robertson *et al*., 1976) [56]. An air blast tunnel takes 15–20 min to freeze peas (Fellows, 1990) [22] as compare in immersion freezing take less than two min to freeze the peas in a ternary solution (Cipoletti *et al*., 1977) [12]. Immersion freezing causes less product dehydration and a higher quality final product is obtained (Lucas *et al.*, 1996) [44].

Immersion freezing, using a liquid coolant as a heat-transfer medium (Lucas *et al.*, 1998) [45], can drastically increase freezing speed (Ribero *et al.*, 2009; Boonsumrej *et al.*, 2007; Sun *et al.*, 2003) [55, 9, 62] due to the high thermal coefficient of liquid media used in the 76 IF system (Lucas *et al.*, 1999) [46]. This results in an instantaneous and uniform nucleation throughout foods achieved and small ice crystals are formed (Anese *et al.*, 2012; Zhu *et al*., 2004) [4, 67].

Table 2: Freezing of the different products at different immersion freezing temperature

Food	Immersion solution	Temperature	Dipping Time	Shelf life	Reference
Strawberries	$CaCl_2$	-20 ºC	Cold zone temperature of the fruit reached -18 ºC	-	Galetto *et al*., 2010 [29]
Litchi	Quaternary refrigerant	-35 ºC	10 min	6 months	Liang *et al*., 2014 [42]
Mozzarella cheese	23% Nacl	-15 ºC	180 min	-	Ribero *et al*., 2009 [52]

3.5 Cryogenic freezer

Cryogenic freezers work on the principle of absorption of the heat from the food materials by changing the state of the refrigerant (or cryogen) within the freezer. The energy in the form of heat from the product therefore provides the heat of transformation of vaporization or sublimation of the cryogen. The cryogen with high heat transfer coefficients quickly eliminates heat from all the surfaces of the food by intimate contact, results in the quick freezing of the food products. The liquid nitrogen and solid or liquid carbon dioxide are used as a refrigerant in cryogenic freezer. Dichlorodifluoromethane used as a refrigerant for different perishable products i.e. meat paste, shrimps, tomato slices etc., which are sticky and fragile in nature (Fellows, 1990) [22].

The selection of the refrigerant is based on its technical specifications as well as performance for a specific food product, the cost and availability and its safety with impact on the environment (Heap, 1997) [32]. During cryogenic freezing, the foodstuffs come into contact with the cryogenic liquid and quick freezing of the outer layers occurs forming a thin crust. This freeze crusting treatment is said to provide a higher mechanical resistance to the foodstuffs and to prevent small and/or wet products from sticking on the conveyor or between them. The crust frozen locks in moisture and flavors and prevents clumping. When products are frozen more slowly, as in a mechanical freezer, moisture forms an ice bridge between the individual pieces of food and they clump together. With liquid nitrogen, the pieces are individually quick frozen, and there is no time for the bridging to occur (Agnelli, 2002) [1]. Handling and storage of cryogenic gases can be dangerous. Low temperature hazard and oxygen enrichment/deficiency hazard (Asphyxiation). There may be chances of explosion (Leeson, 1987) [40].

3.6 Individual Quick Freezer

Individual quick freezing technique is designed to freeze each and every piece of food individually from each other's. Generally, smaller pieces of food products for example, kind of berries, diced or sliced fruits and vegetables, non-vegetarian perishable products such as meat, poultry, shrimps, small fish etc., and grains products, even pasta are frozen with IQF technologies (Alfaro, 2017) [2]. There is no formation of lumps in product, creates smaller ice crystals and less mechanical damage of intact cells of the food. Quick frozen

products have better taste, flavour, aroma, color appearance and freshness than slow frozen products (Sebastian, 2014) [58]. Darke *et al.*, (1981) [19] compared the Individual quick freezing and air blast freezing for vegetables and found that vegetables individually quick frozen were superior to common blast frozen vegetables, particularly with regard to reduced drip loss and consumer convenience.

4. Effect of Freezing on the Nutritional Quality of Perishable Food Commodities

Freezing generally not adversely affects the colors, flavors or nutritional and sensory, however the loose may be due to inefficient preparation procedures or may deteriorate later throughout the low temperature storage. Due to destabilization of the food emulsions and precipitation of the proteins from its solution, freezing having less significance in the area of the frozen milk. Whereas, in different bakery products to reduce retro degradation and staling of the product during freezing and low temperature storage, a rich proportion of amylopectin is required within the starch (Fellows, 1990) [22]. Air tight packaging is also an effective means to eliminate freeze burn from the frozen food products. Freeze burn could be take place when frozen foods have been damaged by dehydration and oxidation, because of air transfer to the food. The wrapping of the frozen food in the packaging material having high moisture-vapor-proof property can prevent the same issue in the frozen products. The air elimination from pack foods prior to freezing preserve a certain types of fruits from browning by adding ascorbic acid (Willenberg *et al.*, 2009) [65].

4.1 Effects of the freezing on the nutritional value of perishable food commodities

According to Selman (1992) [59], the method of freezing itself doesn't change the nutritive value of the product being frozen. The blanching as a preparative steps before and freezing and subsequent frozen storage are responsible for the losses of the more labile vitamins. No change in thiamin and riboflavin contents of broad bean seeds was observed, after freezing. This result can also be true for the other components of different fruits and vegetables (Lisiewska *et al.*, 1991) [43]. Thane and Reddy (1997) [63], reported that carotenoids content is generally not affected particularly by instant freezing of the product. Mullen *et al*., (2002) studied the effect of freezing on anthocyanins as well as flavonoids content of red raspberries and reported that, no significant difference was observed in total flavonol content of fresh and frozen raspberries product (22.3 – 27.0 n moles/g fresh weight). As far as anthocynin is concern, the levels of the individual and overall anthocyanins content from the six vital anthocyanins were found non significantly different in the fresh and frozen raspberries. A minor change in the ellagic acid, total phenol content, ascorbic acid (vitamin C) content, and antioxidant capacity was observed in Spanish raspberries after freezing. Although, major part of the scientific study analyzed that the nutritional value and composition of fruits and vegetables were not greatly influenced by freezing (De Ancos *et al*., 2000) [14].

4.2 Effects of pre-freezing treatments on the nutritional value of perishable food commodities

Thane and Reddy (1997) [63] suggested peeling of the peaches, tomatoes and carrots before processing. The peeling of such fruits can be done by using hot water, lye solution or mechanical peelers. Some of the nutrients may also be eliminate from the peeled products by these processes.

Blanching as a pre-freezing process inactivates enzymes which generally affects the pigments, flavor, nutritive and sensory value during low temperature storage (Fennema, 1982) [23]. Spiess (1984) [61] suggested that by keeping time and temperature combination at an optimum during blanching, the retention of the water-soluble vitamins and minerals can be maximized. In case the balancing of almost every vegetable, heat is utilized for a optimum period of time followed by fast cooling before freezing. Blanching, depends on the size of vegetable and done at the temperature between 75 and 95 ºC for 1 to 10 min (Holdsworth, 1983) [34]. Steam blanching helps to retain more water-soluble nutrients, like some vitamins and minerals than hot water, though takes longer time to blanch (Barbosa-Cánovas *et al*., 2005; Fennema, 1982) [8, 23]. The degradation of the heat liable nutrients can be minimized by rapid cooling of the product, after blanching (Barbosa-Cánovas *et al*., 2005) [8].

Table 3: Effect of blanching and freezing on fiber, phenolic compounds and minerals retention (%) in different vegetables

Vegetables	Soluble fiber	Insoluble Fiber	Total dietary Fiber	Total Phenolics	Ca	Mg	K	P	Na
Peas	149	106	107	79	114	97	80	94	130
Carrots	115	125	120	92	119	110	98	106	88
Cauliflower	113	109	110	87	100	89	84	87	87
Cabbage	154	118	125	126	-	73	-	-	-
Spinach	88	112	108	-	109	91	64	87	60
Potato	83	111	97	71	75		84	90	-

***Source*:** Puupponen-Pimia *et al*., 2003 [54]

Puupponen-Pimia *et al*. (2003) [54] analyzed the effect of different blanching conditions on fiber, minerals and phenolic compounds. The authors worked particularly on the water and steam balancing of the vegetables, followed by rapidly freezing at -40 ºC. Authors concluded that blanching stage is whole responsible for differences in the nutrients and compounds analyze within the final product. Authors also concluded that dietary fiber components of vegetables were found unchanged after the blanching treatment. The reason behind stability of fiber after blanching within the processed material may be due to washing of soluble components and little molecules concentration of fiber components. Another reason may be the mechanical disruption of cells during processing which may have resulted in better extraction of fiber components (Table 3).

Among all the minerals, potassium contents were reduced particularly in the spinach throughout the blanching treatment. Puupponen-Pimia *et al*. (2003) [54] also studied the behavior of minerals solubility throughout the blanching treatment. Because of high solubility index of potassium in water, is lost by leaching during blanching treatment. Calcium and magnesium are not usually lost by leaching because of the tendency to bind with the plant tissues and even can even be absorbed by vegetables from hard water used for blanching

treatment. Usually, about 20-30% total phenolic may be decreased during blanching process (Table 3).

5. Effects of Freezing Systems and Storage Temperatures on Overall Quality of Perishable Food Commodities

Usually, foods can be stored safely at a temperature of -18 ºC, however, this low temperature storage and/or for long period of time can cause vitamin losses and adverse quality effects on color and flavor of the product at retail level. However, during frozen storage the losses in vitamins depends on the type of product, packaging used and additives or sugar used (Fennema, 1982) [23].

5.1 Effects of freezing systems and storage temperatures on nutritional quality of perishable food commodities

Effect of frozen storage at -20 ºC for 6 months on pH and acidity of peas was studied by Forni *et al*., (1991) [26]. The author concluded that blanching and freezing of peas caused losses of acidity ranging between 32% and 70% with respect to the fresh peas' whereas pH values consequently increased during processing. Further decreases in acidity, ranging from 20-30%, were noticed during storage. Same results were found by Cano *et al*., (1993) [10], who studied the effect of freezing on four Spanish kiwi fruit cultivars. The kiwi fruits first washed, peeled and sliced (6-8 mm) and then transferred to air-blast freezer for freezing at a temperature of -40 ºC. The authors concluded that during the entire freezing process the total acidity of the fruit slices slightly reduced. However, the total acidity of kiwi fruit slices (monty variety) reduced 20% in comparison with the total acidity of the raw fruit. Jaworska *et al.*, (2009) [36] showed a significant fall in total acidity compared to the raw mushrooms frozen stored at -35 ºC. Similar results were found by Sarahi *et al*., (2004) [57] for frozen strawberry. They also observed a decrease in acidity of strawberry during frozen storage at -18 ºC but the effect was not so great.

Sahari *et al.*, (2004) [57] analyzed the impact of low temperature on ascorbic acid content of strawberries. Authors observed a significant decrease in the ascorbic acid content of the product i.e. 64.5%, 10.7%, and 8.9% when stored at -12, -18, and -24 ºC respectively, after 90 days of storage. The effect of low temperature storage at -18 ºC for 12 months was also studied on the ascorbic acid content of four Spanish kiwi varieties. However, the loss of ascorbic acid was observed in all the varieties during storage, whereas, bruno variety has been showed the most significant decrease in the ascorbic acid i.e. 37% (Cano *et al*., 1993) [10]. Similar results found by Myojin *et al*., (2008) [50], Lee *et al.*, (1946) [36] and Poiana *et al*., (2010) [53]. All the authors observed a decrease in ascorbic acid content during frozen storage. Fennema, (1982) [23] analyzed the effect of the subfreezing temperatures on the speed of ascorbic acid degradation in vegetables and concluded that a rise in temperature of 10 ºC, inside the range of -18 to -7 ºC, increases

Table 4: Effect of freezing systems and storage temperatures on pH, acidity, ascorbic acid, total phenolic content and anthocyanin content of perishable food commodities

Product	Freezer	S. Temp	S. Time	pH	Acidity	Ascorbic acid	TPC	Anthocyanin	Reference
Peas	IQF	-20	F.F	7.04	5.13	-	-	-	Forni, *et al*., 1991[26]
Peas	IQF	-20	6	7.46	3.45	-	123	-	Forni, *et al*., 1991[26]
Kiwi	Air blast	-18	12	3.35	1.55	-	-	-	Cano, *et al*., 1993 [10]
Kiwi	Air blast	-18	12	2.88	1.91	-	-	-	Cano, *et al*., 1993 [10]
Kiwi	Air blast	-18	12	3.22	1.60	-	-	-	Cano, *et al*., 1993 [10]
Kiwi	Air blast	-18	12	3.17	1.52	-	-	-	Cano, *et al*., 1993 [10]
Mushrooms	Air blast	-35	12	-	0.97	-	-	-	Jaworska, *et al*., 2009 [36]
Strawberry	Domestic	-18	03	-	1.15	-	-	7-.69	Sahari *et al*., 2004 [57]
Bitter gourd	IQF	- 40	06	-	-	68.6	251.6	-	Myojin *et al*., 2008 [50]
Peas	Air blast	- 06	06	-	-	0.15	-	-	Lee *et al*., 1946 [39]
Snap Beans	Air blast	-06	06	-	-	0.11	-	-	Lee *et al*., 1946 [39]
Raspberry	IQF	-18	06	-	-	26.22	103.65	-	Poiana *et al*., 2010 [53]
Blueberry	IQF	-18	06	-	-	6.61	458.54	-	Poiana *et al*., 2010 [53]
Blackberry	IQF	-18	06	-	-	5.28	191.12	-	Poiana *et al*., 2010 [53]
Bitter Gourd	IQF	-40	06	± 6.1	-	-	-	-	Myojin *et al*., 2008 [50]
Cherry	IQF	-23	06	-	-	-	960	8.02	Chaovanalikit *et al.*, 2004 [11]
Cherry	IQF	-70	06	-	-	-	-	56.04	Chaovanalikit *et al.*, 2004 [11]

Where, S. Temp=Storage temperature in ºC, S. Time= Storage time in months, Acidity in %, Ascorbic acid in mg/100 g, TPC= Total phenolic content in µmol GAE/100g), F.F. is freshly frozen.

ascorbic acid degradation by a factor of 6 to 20 times, whereas in fruits such as peaches, boysenberries, and strawberries, rate of degradation is raised by a factor of 30 to 70 times.

The total phenolic contents in fresh berries, after freezing and during the 10 months storage period was studied by Poiana *et al*., (2010) [53]. At the end of frozen storage period, total phenol content decreased up to 28.37% for blueberry, 42.41% for blackberry and greatest losses (47.42%) were found for raspberry. Myojin *et al*., (2008) [50] also observed a decrease in total phenolic content of bitter gourd during 6 months of frozen storage at -40 ºC. The author also concluded that blanching of bitter gourd prior to freezing leads to increased loss of phenolic content than unblanched bitter gourd. Chaovanalikit *et al.*, (2004) [11] also observed a considerable decrease in total phenolic content during storage at –23 °C, about 25% degradation after 3 months and 50% after 6 months. Anthocyanin contents showed significant differences at all temperatures and between the two freezing methods. In quick freezing, the food colorant changed and change was probably due to replacement of anthocyanin pigment in quick freezing (Chaovanalikit *et al.*, 2004) [11]. The authors also analyzed the effect of frozen storage on anthocyanin content of cherries and concluded a degradation of 87% was observed in anthocyanin content when stored at -23 ºC for 6 months with an increase in the polymeric color (from 12.5 in fresh cherries to 61% after frozen storage); whereas storage at -70 ºC resulted in much greater anthocyanin stability with 88%

remaining after 6 months. De Ancos *et al.*, (2000) [14] found no change in raspberry's monomeric anthocyanin content when stored at -20 ºC temperature up to one year. Hager *et al.*, (2008) [31] were also observed the same results for monomeric anthocyanin and polymeric color in frozen blackberries (individually quick frozen) and stored at -20 ºC temperature for six months.

5.2. Effect of freezing systems and storage temperatures on physiochemical quality of perishable food commodities

Cano *et al.*, (1993) [10] studied the effect of frozen storage on moisture content of kiwi fruit. The Kiwi fruit slices (slice dimensions 6-8 mm) were frozen at -40 ºC temperature in an air-blast freezer without any pre-freezing preparation. The slices were left in the freezer until their centers had reached -24 ºC, which takes approx. 15 min. The freezing process did not produce a significant dehydration of monty and hayward kiwi fruit, whereas bruno and abbot frozen slices showed a slight decrease in moisture content at the end of storage (12 months). The frozen kiwi fruit slices showed significantly different moisture

Table 5: Effect of freezing systems and storage temperatures on moisture content, dry matter, color and firmness of different fruits/vegetables

Product	Freezer	S. Temp	S. Time	M. C.	D. M.	Color			Firmness	Reference
						L	A	b		
Peas	IQF	-20	F.F.	-	20.48	-	-	-	-	Forni, *et al.*, 1991 [26]
Peas	IQF	-20	6	-	20.01	-	-	-	123	Forni, *et al.*, 1991 [26]
Kiwi	Air blast	-18	12	82.75	16.37	-	-	-	-	Cano, *et al.*, 1993 [10]
Kiwi	Air blast	-18	12	81.08	16.38	-	-	-	-	Cano, *et al.*, 1993 [10]
Kiwi	Air blast	-18	12	80.86	16.22	-	-	-	-	Cano, *et al.*, 1993 [10]
Kiwi	Air blast	-18	12	80.86	16.98	-	-	-	-	Cano, *et al.*, 1993 [10]
Mushrooms	Air blast	-35	12	-	9.58	57.43	2.03	14.87	-	Jaworska, *et al.*, 2009 [36]
Peas	Still air	-15	04	82.82	-	-	-	-	-	Hung *et al.*, 1983 [35]
Barhi dates	Cryogenic	-40	09	-	-	53.9	10.7	42.2	-	Alhamdan *et al.*, 2016 [3]
Eggplant	Air blast	-20	15	-	-	64.0	1.7	23.0	-	Maestrelli *et al.*, 2003 [47]

Where, S. Temp=Storage temperature in ºC, S. Time= Storage time in months, M.C. = Moisture content in %, D.M. = Dry matter in%, Firmness in kg. and F.F. is freshly frozen.

content from the raw fruit; only monty frozen slices appeared to have similar values to those of raw fruit after this time. Similar results found by Hung *et al.*, (1989) on peas, there was no significant difference in the moisture content of the frozen peas at -15 ºC during 48 weeks of frozen storage (Table 5). Effect of frozen storage at -20 ºC for 6 months on dry matter of peas was studied by Forni *et al.*, (1991) [26]. The author concluded that during storage the increases of dry matter ranged from 5% to 15% on the initial value, whereas Cano *et al.*, (1992) [10] concluded that the dry matter of frozen kiwi fruit slices stored at -18 ºC for 12 months did not change significantly during frozen storage. Jaworska *et al.*, (2009) [36] studied the effect of frozen storage at -35 ºC on the Mushrooms. The results obtained for blanched or soaked and blanched mushrooms showed significant decreases in dry matter content (4–10%) (Table 5). Forni *et al.* (1991) [26] studied the effect of frozen storage on the color of peas. The freezing of peas was done using IQF and frozen peas were stored at -20 ºC for 6 months. The author concluded that the color did not change during frozen storage. While Alamdan *et al.*, (2016) [3] concluded that there is a significant difference in the color of barhi dates during 9 months frozen storage. Results revealed that the color values i.e. L*, a* and b* of frozen fruits had changed with the prolonged frozen storage which extended for nine months. The L* values of the frozen fruits decreased at the end of the frozen storage to 53.9, while, a* values increased during the same period to 10.7, 14 and the b* values followed the same behavior of L* and decreased to 42.2. Same results obtained by Jaworska *et al.*, (2009) [36] who studied the effect of frozen storage on mushroom up to 12 months of storage, resulted in deduction in the lightness (L*). Furthermore, the frozen mushrooms had a higher a* value than raw mushrooms. Similarly Maestrelli *et al.*, (2003) [47] also observed a decrease in lightness (L*) and increase browning during frozen storage of eggplant (Table 5).

5.3 Effect of freezing systems and storage temperatures on sensory quality of perishable food commodities

Sensory evaluation of frozen mushrooms was done by Jaworska *et al.*, (2009) [36] stored at -35 ºC using 5 point method. After one year of storage, the general evaluation of products having undergone pre-processing prior to freezing was 0.2–0.6 points lower than the corresponding products evaluated directly after freezing. The smallest changes were in the product blanched in water (BW). The storage time had a negative effect on indicators such as color, texture, aroma and taste, the values for which were, respectively, 0.4–0.7, 0.4, 0.4–0.9, and 0.2–0.9 points lower than those for the product evaluated directly after freezing. Sarahi *et al.*, (2003) studied the effect of frozen storage on strawberry at three different

Table 6: Effect of freezing systems and storage temperatures on appearance, flavour, texture and overall acceptability of perishable food commodities

Product	Freezing	S. Temp	S. Time	Appearance	Flavour	Texture	Overall acceptability	Reference
Mushrooms	Air blast	-35	12	4.9	4.1	3.6	4.3 (5 point scale)	Jaworska *et al.*, 2009 [36]
Strawberry	slow	-24	03	8.2	5.2	7.1	7.5	Sarahi *et al.*, 2004 [57]
Peas	IQF	-20	06	-	-	-	6.5	Forni *et al.*, 1991[26]
Mango slices	Still	-	12	6.2	6.5	5.9	6.1	Isaacs, 1986
Barhi Dates	Cryogenic	-40	09	5.75	6.40	5.85	6.20	Alhamdan *et al.*, 2016 [3]

Where, S. Temp=Storage temperature in ºC, S. Time= Storage time in months, Sensory data are 9 point hedonic scale

temperature i.e., -12 ºC, -18 ºC and -24 ºC. The sensory evaluation results showed that the effect of freezing method on desirability after storage (with the exception of texture) was not important while, at -
12 ºC desirability and quality of frozen strawberry decreased. Also, samples stored at -18 ºC and -24 ºC maintained the highest degree of quality based on color, texture, flavour and wholeness; the sample maintained at -12 ºC was not acceptable. Effect of frozen storage on overall acceptability of peas stored at -20 ºC was evaluated by Forni *et al*., (1991). The stored frozen peas were judged acceptable by the panel test. After 6 months of frozen storage, no statistically significant differences were noted in appearance; however, there was an improvement in acceptability (Table 6).

5.4 Effect of freezing systems and storage temperatures on hardness, elasticity, resilience and chewiness of perishable food commodities

Alhamdan *et al.*, (2016) [3] studied the effect of frozen storage on textural properties of barhi dates. Three freezing methods such as a cryogenic freezing (CF), individual quick freezing (IQF) and conventional slow freezing (CSF) were used for freezing of the dates. The frozen date products were stored at low temperature storage for nine months. Generally, the textural parameters were dependent on the method of freezing used and decreased as the storage time was increased. During first three months of storage, hardness values of the fruits reduced to 59.8%, 71% and 74.17% using cryogenic freezing, individual quick freezing and conventional slow freezing, respectively. The authors also analyzed that throughout the storage period from three to nine months, the values of frozen fruits hardness were deceased by 12.1% and 13.17%, using cryogenic freezing and individual quick freezing methods, respectively. By using cryogenic freezing, individual quick freezing and conventional slow freezing processes, resilience values of fresh fruits reduced by 36.8%, 40.27% and 41.69%, respectively. The authors also concluded that using the three studied freezing methods, elasticity values of the frozen fruits stored for different times of frozen storage were non significantly different with each other. Deterioration in texture of barhi fruits was found less in cryogenic freezing method and found similar to fresh like texture of the fruits. Therefore, cryogenic freezing method was found more suitable as compared to individual quick freezing and conventional slow freezing as textural quality of barhi fruits were concerned. Similar results were found by Hung *et al.*, (1983) [35], who studied freezing effect on texture of peas. There were no significant differences in tenderness and chewiness of peas that were processed by air-blasted and stilt-air freezing methods.

5.5 Effect of freezing systems and storage temperatures enzymatic activity of perishable food commodities

The enzymatic activity of frozen barhi dates were also evaluated by Alhamdan *et al.*, (2016) [3] and revealed that barhi dates were generally frozen using three methods i.e. cryogenic freezing (CF), individual quick freezing (IQF) and conventional slow freezing (CSF). Though in the above freezing methods the increase in the enzyme activity of fruits take place but maximum increase observed in the conventional slow freezing. This enzymatic activity within the fruits may be just because of the elimination of blanching treatment from the schedule. However, it is also analyzed by the authors that within the first three months the slow rate of the enzymatic activity of both the enzymes in fruits was observed. After that, within the next three months the enzymatic activity of fruits increased unexpectedly whereas, during the next last three months it was found almost constant. For CF and IQF methods, during a period of nine months storage under low temperature, though the activity of the enzymes increased but the rate of increase was found a very slow. These enzyme activities may be responsible for the quality deterioration of fruits i.e. fruit texture and color, during storage.

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