**4.3.1. Freezing Methods**

**4.3.1.1. Contact Freezing**

Packaged products placed between 2 metal plates that are cooled internally are frozen by contacting the plate. Besides, food itself provides some heat transfer from frozen outer side to unfrozen inner side. The product to be frozen in this way must be properly packaged. In order to ensure good heat transfer into the packaging, the packages are filled with food material so that there are no gaps. The thickness of the food must be the same for the freezer plates to fully contact the food and to apply homogeneous pressure to the food. In this method, fast freezing can be done if the thickness of the food to be frozen does not exceed 50 mm[37].

**4.3.1.2. Air-blast (airflow) Freezers**

It is the oldest known method and is applied in 3 different ways[37-40].

* Tunnel freezers: Packaged foods placed on trays and trays on wagons. Wagons may be moved by workers or mechanically. The air moves rapidly between the food and the evaporator with powerful fans. The movements of product and air can be parallel or opposite.
* Spiral belt air-blast freezers: Principally very similar to tunnel freezers. Moving belts passes in front of evaporators in a circular movement. Foods placed on the belt and after completing tour foods leaves freezer. Number of bands can be as high as 30. Air movement can be horizontal or vertical.
* Fluidized bed air-blast freeze (IQF): This technique is suitable for small and homogenous fruits and vegetables such as peas, corn, cherry, strawberry. Air at ca. -400C is passed at high velocity (5m/s or more) up through 3-14 cm bed through perforated base. Thus, all surfaces of the particles come into contact with cold air and the products freeze as grains. Main advantages this technique are providing very fast freezing and pieces are not stick each other, Technique is not suitable for packaged and large pieces of fruits and vegetables. The method is also called as Individual Quick Freezing (IQF). Although cold air freezing is the most widely used freezing method, it also has some disadvantages such as moisture loss, weight loss and freezer burn.

**4.3.1.3. Immersion Freezing**

While the raw material to be frozen is moving over a belt, it is passed through the cooled brine solution or the brine is sprayed onto the product. This technique is more suitable like chicken etc. It is used for surface freezing of foods. Final freezing is carried out in an air flow. In this method, the product must be covered with a quality waterproof packaging material. Besides brine (salt water), sugar syrup and glycerol solutions can be used as freezing solution[38].

**4.3.1.4. Cryogenic Freezing (Freezing with Liquefied Gases)**

Fastest freezing can be achieved with this method. Liquid nitrogen (most commonly used, boiling point -196°C, inert, non-toxic, inexpensive) and liquid carbon dioxide (boiling point -145°C) are the gases used. Liquid nitrogen is sprayed on the product, which is placed on the belts in a stainless steel insulated tunnel, from a tip near the outlet. The evaporating gas disperses into the tunnel and is collected at the exit of the tunnel. There is a reverse current principle. This method is very convenient for continuous freezing[35,41].

**4.4. Processes Applied After Freezing**

Treatments such as sorting and calibration can be done for after or before freezing depending on product. In some raw materials, if these processes are done before the freezing process, quality loss occurs due to damage. For this reason, soft raw materials that are susceptible to damage are sorted and calibrated after freezing, thus minimizing quality losses due to such damages. Frozen raw materials are calibrated according to their size. It is usually a mandatory process in terms of standards that vegetables and fruits have the same characteristics and size.

**4.5. Packaging**

Frozen vegetables and fruits are packaged to protect them from external factors, to provide ease of transportation, storage, distribution, and to perform marketing and promotion functions. In frozen foods, 2 packages are used inside each other. Consumer packages that come into direct contact with food are called "inner packaging", and packages that hold the inner packages together and provide ease of transport are called "outer packaging". Inner packaging materials are mostly plastic-based, such as polyolefins, polyesters, and bag materials. Paper, cardboard and cardboard-based packages are used for outer packaging[42].

**4.6. Storage**

The storage of frozen products is as important as its production. For this purpose, the product should be stored at least -18/-20°C. In general, the preservation of the characteristic features of foodstuffs such as taste and smell in cold environments that will prevent them from deteriorating until consumption is defined as the "cold chain" and in the frozen food sector, these cold chain foods are frozen at -40°C at -18°C until consumption. It requires storage and transportation in a reduced temperature environment[42].

The temperature in the frozen storage is usually -18°C. However, -30 °C is ideal for better quality. It is important that the storage temperature is low as well as being stable.

The changes that may occur in the frozen product during storage are as follows[7,15,42];

* Recrystallization of ice: It is any change in the number, size, shape and orientation of the crystals formed by the transformation of water in the frozen food into solid phase. The main reason for this is the temperature fluctuation. The advantages of fast freezing are lost as a result of recrystallization, ice crystals grow and tissue is damaged.
* Enzymatic changes: Enzymes such as lipase, lipoxygenase, peroxidase, polyphenol oxidase and cystine lyase cause significant changes in sensory qualities such as color, taste and smell, and these enzymes are still active at low temperatures and form off-flavors as a result of their activities. While this variation can be minimized by boiling the vegetables, this problem may occur because the fruits are not boiled.
* Protein denaturation: The variable temperature causes the water attached to the protein molecule to separate from the molecule. The physical and chemical changes that occur are irreversible.
* Ice formation in packaging and storage: The reason is sublimation, and water condensation in inner layer of package.
* Freezer burn: This is due to sublimation. When the water is separated, the pigment concentration in the food increases proportionally. As its level increases, the texture becomes leathery.
* As the storage temperature increases, nutrient losses increases.

Most resistant organisms are molds to low temperatures (they can work down to -18°C), yeasts cannot operate below -12°C and bacteria below -10°C. Pathogenic microorganisms cannot grow under 3°C.

**4.7. Thawing**

The most important problem in frozen cellular products is drip-loss (loss of tissue fluid through dripping). The thawing process is not the reverse of the freezing process. In the freezing process, the heat transfer is from the ice with a high thermal conductivity coefficient (2.25 W/m2K) to the water, while in the thawing process, the heat transfer is from the water with a low thermal conductivity coefficient (0.57 W/m2K) to the ice and therefore takes longer[43,44].

In the thawing process, there may be microbial risk as the temperature will remain around 0°C for quite a long time. If frozen food is to be consumed by cooking, it is ideally poured directly into boiling water (if it is in small pieces, it can be added into the oil). However, if there is no cooking, as with fruits, it can be thawed at refrigerator temperature. Meanwhile, sensory properties, especially texture, deteriorate due to drip-loss, and nutrient loss occurs. For this reason, frozen fruits cannot be consumed directly, but are used in the production of other products (jam, yogurt, ice cream etc.)[45,46].