FREEZE-THAW

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Abstract

The freeze-thawing technique helps to efficiently dry various food items while marinating the quality of the food intact. The paper reviews the FT process, its application and its advantages and disadvantages with an extensive review of existing literature. Alterations of FT pre-treatment provide positive results regarding the moisture level of foods and effective diffusivity, as well as a significant decrease in the drying time. It is also applied for various types of drying processes such as hydrogel formation, modification of scratch, soft candy production and so on. Certain disadvantages regarding the controlling of crystallisation during the freezing and thawing technique are highlighted. However, reviewing various articles and alternative processes for food preservation, the FT technique is efficient and beneficial in retaining the taste, flavour and nutrient content of the food items.

Keywords: Freeze-thawing, food processing, drying process,

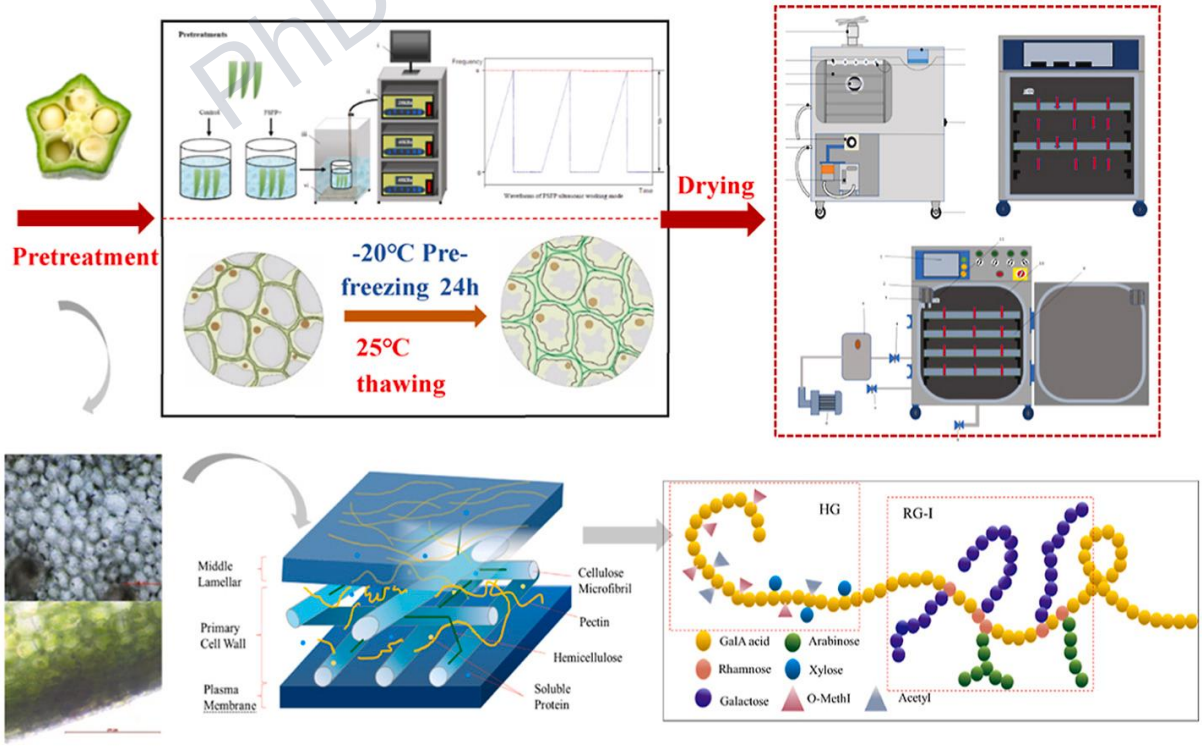
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Introduction

Improvement of drying rate with freeze-thaw (FT) helps to modify the capacity for cell membrane's permeability, alienating the osmotic pressures and destroying the wall structure of the cell. The primary principle of FT is based on ice crystallisation, capable of piercing into the cell wall while the expansion process of frozen water is occurring. For example, the process of FT on weathering on the outer surface rocks is considered to be a complex process which is identified by the intermingling of the rock properties and its interaction with the dynamic environment (Deprez *et al.* 2020). Multiple processes for thermal drying can be beneficial with the help of FT pre-treatment, which not only helps the destruction of the cell wall but also ensures the prevention of structural deformation during the drying process. Thus, the paper reviews the process, application and advantages of FT with an extensive review of existing literature to introduce a comprehensive and concise piece on the process.

Alterations of FT pre-treatment have been seen, which provide positive results regarding the moisture level of foods and effective diffusivity, as well as a significant decrease in the drying time. As per the words of Xu *et al.* (2021), the drying process of okra is complex as the vegetable is rich in nutrients, pectins and moisture content, making the shelf life very short. Thus, FT and ultrasound (US) pre-treatments are recommended using various drying methods such as hot air drying (HD), vacuum pulsed drying (VPD) and vacuum freeze-drying (VFD), indicating that FT and US pre-treatments had been highly beneficial for the drying process.



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Figure 1: drying process for okra using FT and US pre-treatments

(Source: Xu *et al.* 2021)

However, different types of drying processes can exhibit different impacts on the tissues such as heat pre-treatment may lead to degradation of the heat-labile compounds, while the adverse impact is seen based on specific combinations of drying processes and FT on the food quality. The paper, therefore, assesses these research problems to identify the different types of drying processes that are beneficial to FT.

Applications of freeze-thaw in food processing

The application of freeze-thaw for food processing helps to enhance the drying efficiency and preserve the quality of dried products. FT processing is seen widely for meat products however, FT pre-treatments for fruits and vegetables have also introduced beneficial results. For example, the FT pre-treatment was beneficial for lotus root drying, providing favourable results regarding drying kinetics. On the other hand, FT processes further increased the thermal stability of dried garlic, reducing the drying time by time 22.22%–33.33% and 14.25%–15.50% reducing energy consumption due to porous structure formation, increased free water and water loss (Feng *et al.* 2020). Therefore, FT is considered a beneficial alternative to traditional food processing techniques as it helps to enhance the shelf life of foods without significantly altering their quality.

The applications of FT are illustrated below:

Hydrogel/ cryogenic

FT is regarded as a simple approach which can be applied to producing polymeric hydrogels or cryogens. The formation of cryogenics is dependent on freezing and thawing. Freezing temperature set at −5 to −20 °C is used for freezing polymer solutions, leading to the crystallisation of solvents and unfrozen liquid microphase (ULM) formation. The ULM formed in the polymer molecules, after the formative growth of ice, are essentially induced and aligned. After that, the thawing process is initiated, where the polymer chains remain unchanged or intact, despite the melting ice, forming cryogens within an interconnected structure of microporous. These cryogens can also be influenced by various factors such as polymeric concentration, the weight of molecules, pH level, duration and temperature of freezing, and rate of thawing and thawing cycles. As stated by Saqib *et al.* (2022), the formation of hydrogel beads is safe to use during food processing as it is generated from natural food colloids, making it nontoxic, safe and biocompatible. It is also used for enhancing the attractiveness of food as it can be customised based on the required shape, colour texture and so on (Saqib *et al.* 2022).

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Furthermore, hydrogel beads are also characterised by targeted delivery, diversity, easy fabrication and so on. Therefore, the process of forming hydrogels with FT can enhance the efficiency of food processing without compromising the quality, taste or texture of food items. The hydrogel bead is essentially a three-dimensional, spherical structure of a colloidal system which helps the active materials to be dispersed and surrounded by protective shells that can perform various functions. According to de Lima *et al.* (2019), despite the simplicity of using the FT techniques for producing hydrogels that are crosslinked, it may lack sufficiency for the modification of arrangement on the three-dimensional polymeric network during the drying process, using water removal. Polyvinyl alcohol hydrogels are recommended to be used for generating efficient cryogenic spheres, based on a modified FT cycle. On the other hand, Hellebois *et al.* (2022) articulated the example of whey protein's (WPI) capacity of forming cryogen influenced by alfalfa galactomannan (AAG) indicating that AAG controlled the changes of WPI cryogen microstructural FT processes, as AAG contributed to the improvement of water retention ability. Emulsion-filled gel (EFG) is also considered a process of application related to FT, in which oil droplets are embedded into the gel matrix. It is considered to be an efficient alternative for gel properties, where the balanced interaction between gel matrix and emulsion can benefit the flavour and taste during the storage period.

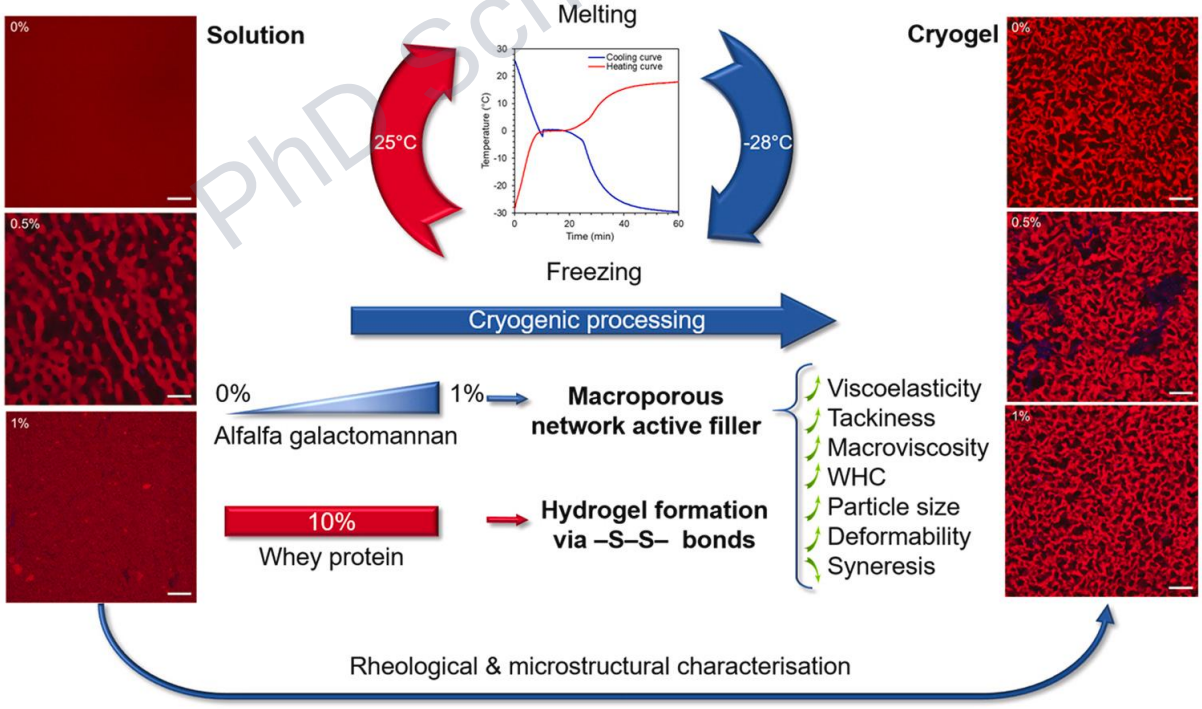


Figure 2: cryogen solutions of microstructural characteristics

(Source: Hellebois *et al.* 2022)

Modification of starch

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Process for starch modification with FT is conducted based on the purpose of use. As starch is considered to be a widely available commodity within the agricultural sphere and used in processes and products of foods, the industrial application of modified starch has increased significantly. For example, paper manufacturing uses cationic starches and starch phosphate esters for film-forming properties and adhesive purposes. Adhesive from dextrinized starches is also used for glass and metal. The textile industry also uses oxidised, esterified, hydroxyalkyl and acid-modified starches. As per the words of Wang *et al.* (2020), using ultrasound for an FT treatment to modify starch can be used as a lipophilic heat-resistant absorbent with an 80.2% enhancement of oil absorption capacity. The multi-purpose use of modified starch using 7UT-FTS is recognised as more efficient than native starch.

Freezing treatments can significantly impact the characteristics and functions of the starch during its modification. As stated by Tao *et al.* (2015), investigating the properties of waxy rice starch (non-gelatinized) after various cycles of freezing and thawing indicated that 5.77% damage on starch due to freezing was evidenced from 1.36% damage of the native starch. On the other hand, high amylopectin concentration was seen, with a decrease in the crystallinity to 31.34% from 35.19% (Tao *et al.* 2015). Therefore, increased susceptibility due to porous granular surface crystallinity was decreased by the freezing water.

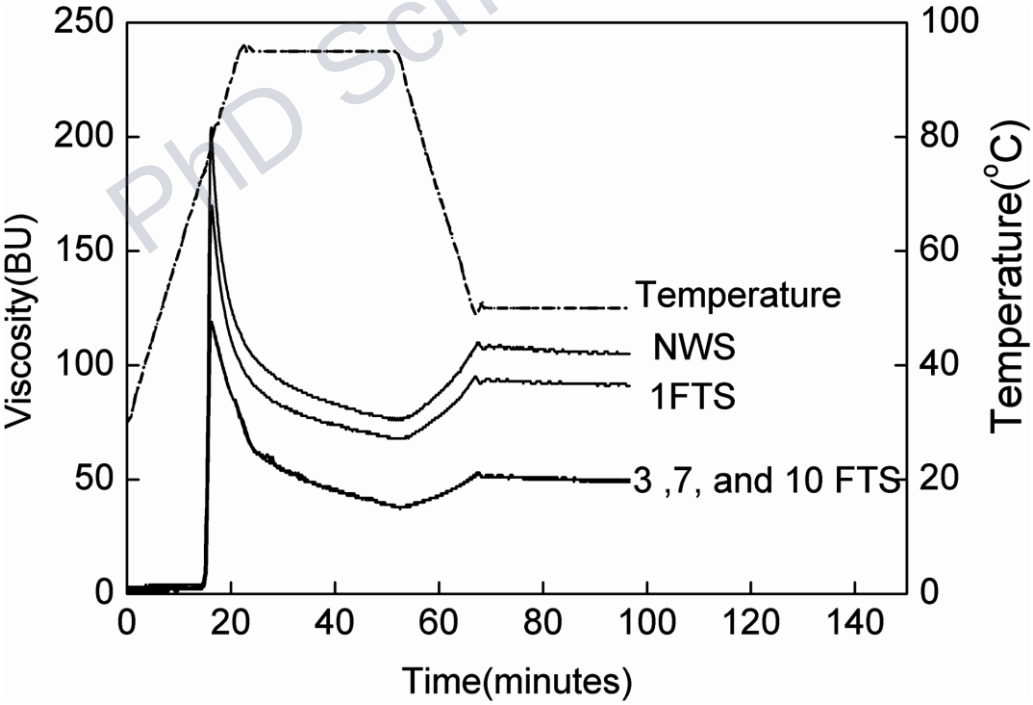


Figure 3: pasting profile of native and Ft processed rice starch

(Source: Tao *et al.* 2015)

In various cases, critical melting (CM) is also attributed to the enhancement of FT's impact on starch granules based on melting point temperature. CM contributes to increased elasticity of

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native starch, promoting swelling and thereby enhancing the mechanical strength of the ice crystals, preventing granular destruction. The practical application of porous starch is dependent on mechanical strength and thermal stability. As per the words of Liu *et al.* (2019), the impact of temperature on the properties of waxy corn starch was significant while the number of the freeze-thaw cycle contributed to the changes in properties. Therefore, the identification of changes in the corn starch structure after FT cycles based on different temperatures contributes to FT's effectiveness that can be used for efficient food processing.

Soft candies

Freeze-thaw technique for producing soft aonla candies Has gained attention and is commercially available in India. Hard-textured candies are less in demand in the current market. As per the words of Kale *et al.* (2019), soft candies using FT treatments provide successful results, tested by applying peak force of fresh (172.25 N) blanching (8.77 N), freezing (1.06 N) and thwarting (0.85 N) fruit segments. The changes and deformation of the texture of the samples indicated the production of soft candies that are commercially more profitable in the market. On the other hand, industrial production of soft candies and other soft food items is being benefited from the incorporation of FT. As articulated by Ozel and Oztop (2021), magnetic resonance imaging (MRI) and time-domain nuclear magnetic resonance (TD NMR) can be used to alter the texture of the food without disrupting the internal structure. These processes are used majorly in food industries for fast, cost-effective and reliable processes of large-scale food production. Therefore, freezing and thawing applied for food soft candy production has higher potential in the market, ensuring that the quality of the product remains acceptable.

Innovative strategies are being adopted for the industrial production of soft candies. Considering the required texture, flavour and overall quality of the food items, the FT technique can be utilised for enhancing the mechanical properties of the gels used for food factors. As stated by Khalesi *et al.* (2020), the application of FT cycles for adding fillers such as oil droplets or adopting soaking methodology, condensation and alignment of biopolymers within the gel network whereas within the gel network, other fillers and cross-linkers are not necessary to add while applying FT. Therefore, innovative strategies can be utilised by the application of proper FT methodologies for food processing.

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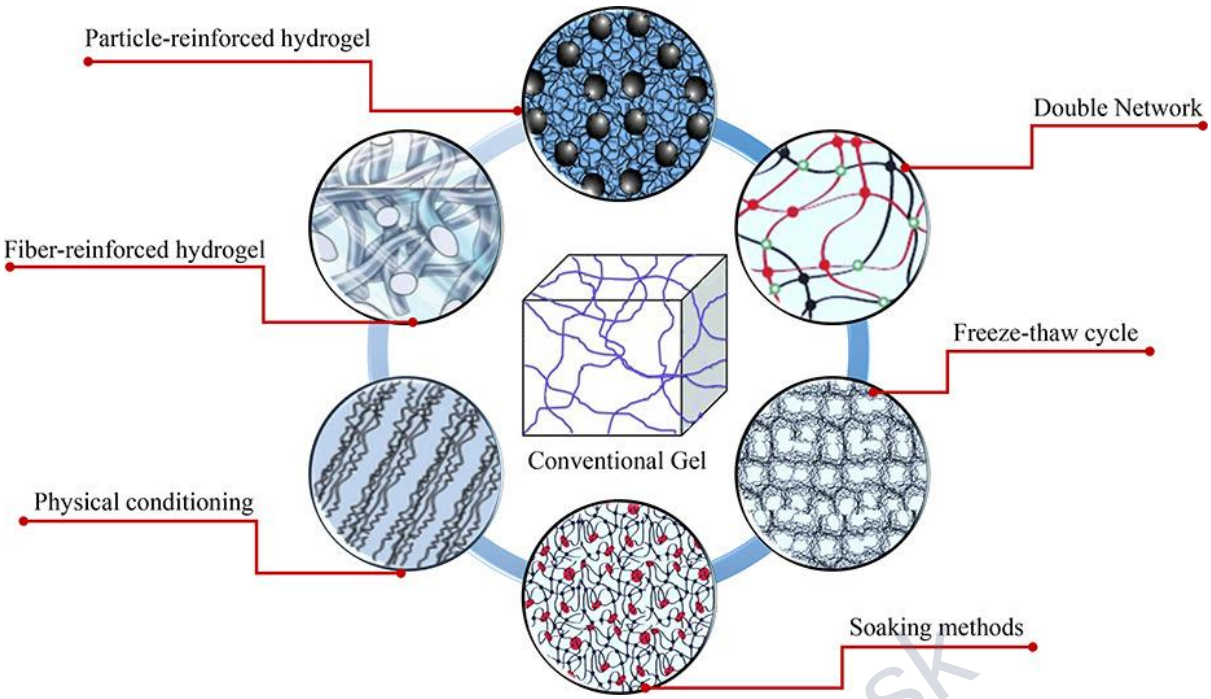


Figure 4: Various methods for innovative food processing strategies and their impact on gel network

(Source: Khalesi *et al.* 2020)

Reviewing different drying techniques

Different types of drying techniques applied within the food industry primarily aim at prolonging the shelf-life of food products and preserving their texture, flavour, nutrients and other properties. The following table illustrates various drying processes that are used and researched widely, indicating the efficiency and effectiveness of such techniques:

Author	***Publication year***	***Research aim***	***Research Methodology***	***Drying technique***	***Findings /results***
Lingayat *et al.*	2020	The paper aims at reviewing various types of solar dryers used for crops	Primary qualitative	Sun drying technique	Sun drying using an Indirect type solar dryer (ITSD) is effective for various types of crops which are influenced by solar radiation, velocity, moisture

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					content, product type and total mass and so on. The fabrication process of passive solar dryers was easier than active dryers. The drying rate was also significantly higher for pre-treated food while the food quality remained intact after drying.
Djebli *et al.*	2020	Aiming at comparatively analysing mixed solar dryers and indirect solar dryers for drying potato slides	Primary qualitative	Sun drying technique	Indirect solar dryers (3 h 40 min) are more efficient, accurate and faster than mixed solar dryers (4 h 45 min). The proposed drying technique was highly efficient for drying bananas, Sultana grapes, chilli peppers, cassava and mango.
Jahanbakhshi *et al.*	2020	Investigating The impact of ultrasound temperature and thermodynamics properties	Primary quantitative	hot air drying	The results indicated effective diffusion of moisture by using ultrasound processes for drying nectarine slices at a different level of temperature

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		for hot air dryer			with a 6.50 × 10–10 to 2.11 × 10–9 m2/s coefficient level. 59.70 to 212.97 kwh/kg was the energy consumption level for the drying process.
Liu *et al.*	2019	Investigating the ultrasound-strengthened hot air-drying technique	Secondary qualitative	hot air drying	The results indicated that a significant reduction in the drying time of pear slices is dependent on the temperature and ultrasonic power used for the hot air. The impact of ultrasonic power and temperature was seen on flavonoids, phenolic, revised ration ratio and so on which was beneficial for increasing the nutrient contents of the slices.
Delfiya *et al.*	2022	The paper aims to review the drying Kinetics of various food materials in	Secondary qualitative	Infrared drying process	The designing process for infrared drying methods is critical and based on various factors such as energy

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		infrared radiation drying			consumption, drying rate, energy activation, moisture diffusion and so on. Infrared drying processes are more effective with the incorporation of other techniques for shorter drying time and preservation of food qualities.
Aboud *et al.*	2019	Investigating the efficiency of infrared applications for heating and food processing	Secondary qualitative	Infrared drying process	Infrared technology for food processing is environmentally friendly, cost-effective, water-efficient and energy efficient. The paper indicates that infrared technology can impact sensory properties, Physico-chemical properties, nutritional values and so on positively.
Kalathingal *et al.*	2020	Analysing the prospect of integrating artificial neural network and genetic	Primary quantitative	fluidized bed drying	The study shows that 50–80°C temperature and 7–9.5 m/s air velocity impacted the parameters of colour differences seen

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		algorithm for optimising fluidized bed drying practices of green tea leaves			during the drying process of green tea leaves, providing optimum results.
Zhu *et al.*	2021	The paper aims to investigate the application of ultrasound to increase the effectiveness of fluidized beds with drying	Primary quantitative	fluidized bed drying	Fluidized bed drying (FBD) is indicated to be a more effective drying methods. A lower rate of energy consumption was exhibited by ultrasound pre-treatment and hot water blanching prior to FBD.
Schiffmann	2020	Drying processes based on dielectric and microwave techniques are explored	Secondary qualitative	Dielectric drying	The study indicates a similarity between dielectric energy and microwave energy used for drying food items, however, both require different mechanisms.
Mousakhani-Ganjeh *et al.*	2021	Reviewing ultrasound, dielectric and other drying processes for	Primary qualitative	Dielectric drying	The paper demonstrates the process of electro-based water removal and drying kinetics

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		food preservation			without significant negative impact on food quality based on electrical energy used for dielectric drying processes such as pulsed electric field (PEF) and electrohydrodynamic (EHD).

Table 1: Article review table

Disadvantages/ drawbacks of freeze-thaw

Maintaining the quality of food based on the freeze-thaw cycle can be complicated as it can damage the quality of food and distort the protein structures and interfere with protein kinetics. As per the words of Tirado-Kulieva *et al.* (2022), challenges related to controlling the shape and size of crystals generated during the freezing process and stabilising the thawing process can be critical to address. In essence, the spectrum controllability for freezing and thawing can demonstrate significant damage to the quality of food items. Thermal hysteresis capacity (THC) modification is needed to modify the morphology of crystals and the recrystallisation process to ensure that positive results are achieved. On the other hand, Kumar *et al.* (2022) articulated that enzymatic and chemical methods used for food preservation can reduce impacting the purity of the product which the freeze-thaw cycles cannot remove. However, the FT process is significantly more efficient than other processes. Jia *et al.* (2022) further point to the disadvantage regarding the lack of control seen during the FT process of ice crystal nucleation and growth. Therefore, the identified disadvantages can considerably decrease the quality of food products, impacting the production of the final product.

Conclusion

Freeze-thaw technique for food processing is considered to be an efficient technique that can preserve food items efficiently. Hydrogel formation, modification of starch and production of soft candies can be achieved with FT procedures. Certain disadvantages regarding the controlling of crystallisation during the freezing and thawing technique are highlighted. However, reviewing various articles and alternative processes for food preservation, the FT technique is efficient and beneficial in retaining the taste, flavour and nutrient content of the

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food items. Therefore, freeze-thawing can be implemented innovatively for strategic and large-scale food production.

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