Journal of Food Engineering 148 (2015) 74–79

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Review

The use of supercooling for fresh foods: A review

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ARTICLE INFO

Article history:
Received 28 March 2014
Received in revised form 22 July 2014
Accepted 8 August 2014
Available online 23 August 2014

Keywords:
Supercooling
Food
Temperature control
Refrigeration
Quality
Storage life

ABSTRACT

Supercooling is a food processing technique which has the potential to significantly increase the shelf life of foods and to reduce wastage of food products from the production and retail sectors of the food cold chain. The process uses storage temperatures below the initial freezing point of the food without the product freezing, which maintains the quality attributes associated with fresh foods. The removal of the freezing process leads to shorter processing times from harvest to delivery to retail as well as lower energy consumption (no latent heat removal) and so lower carbon emissions during manufacture when compared to standard frozen food production.

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1. Introduction

The majority of foods are perishable (e.g. meat, dairy and marine foods) and so require refrigeration in order to achieve an acceptable length of shelf life and to minimise the risk of food borne illnesses. Such is the concern over the health implications of foods that this is the predominant factor which governs the legislative requirements on food producers. Despite the potential hazards of not maintaining foods at the correct temperature it is estimated that worldwide only about one tenth of total perishable food production is refrigerated, with developing countries much more likely to ignore this requirement than developed ones. It is estimated that as much as 25–30% of perishable food production is wasted and most of this wastage could be saved during post-harvest storage by the correct use of refrigeration (Coulomb, 2008; IIR, 2009). Frozen storage in particular has been greatly influential on the design and operation of the modern large-scale food production business. Despite the positives of frozen foods, chilled products are still viewed as being more favourable by many consumers, and so chilled foods can

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http://dx.doi.org/10.1016/j.jfoodeng.2014.08.007
0260-8774/

demand higher prices at the point of sale. This consumer perception is partially based on the belief that chilled foods are fresher, less processed and more convenient for cooking than are frozen foods.

Temperature control is an essential part of food production, delivery and storage in the modern food distribution network. Temperature control is used to increase the length of acceptable shelf life of products by reducing the rates of degradation from microbial sources (spoilage and pathogenic) and from intrinsic factors such as lipid oxidation and enzymatic proteolysis. At all stages of the food chain, temperature of the product must be monitored and controlled for both maximum product quality and to comply with the strict food legislation in effect in the EU for foods of animal origin (meat/fish). The use of chilled or frozen storage allows for not only a greater diversity of products to the consumer but also increases the length of available seasonality and distribution area for foods which would be otherwise unavailable away from the production area.

Recent research into food refrigeration and storage technologies has proposed alternative methods of extending the shelf life of fresh foods, including the use of superchilling (partial freezing) and supercooling (cooling below the freezing point without phase change). A review of superchilling was published by Kaale et al. (2011) while this review will focus on the application of supercooling and its effects on food quality in the scientific literature.

2. Definition of supercooling

Supercooling is the process of lowering the temperature of a product below its usual freezing point without the phase change solidification (formation of ice crystals) occurring. This process has several terms such as supercooled or undercooled (Charoenrein and Preechathammawong, 2010; James et al., 2009; Li and Lee, 2008 and Watson and Leighton, 1926), subcooled (Lucas, 1954), freezing point depression (Chen and Chen, 1997 and Griffith and Ewart, 1995) or Hyo-On (in Japanese papers), (Ando et al., 2007). Material can be maintained in this state at atmospheric pressure with accurate temperature control without ice crystal formation occurring when there is an absence of a crystal nucleus (Aparicio et al., 2008; Bedecarrats et al., 2009; James et al., 2009; Sanz et al., 1999; Yin et al., 2005a,b). Theoretically according to Bedecarrats et al. (2009), Cox and Moore (1997) and Fukuma et al. (2012) a supercooled product is unstable and spontaneous nucleation can occur at any moment. Bedecarrats et al. (2009) describe that the process of ice crystallisation is changeable, as this process may not occur at the same time or temperature in what appear to be identical samples due to slight compositional changes between samples, whereas Fukuma et al. (2012) reported finding sections within the same sample which were both frozen and fresh. Yin et al. (2005a,b) reported that it is very difficult to create supercooling in a solid food, as either the structure of the food provides surfaces for ice crystal growth, or it inhibits heat conduction from the product in comparison to a liquid, however they did report that this is not always the case, as orange juice behaves like a solid food during freezing and shows little supercooling compared to liquids such as milk.

3. Types of food product that supercooling has been used on

The use of supercooling in food refrigeration processes is still relatively new, although it has been used to improve shelf life duration for a variety of foods including vegetables (Fuller and Wisneiwski, 2008; James et al., 2009), fish (Ando et al., 2007; Agustini et al., 2001; Beaufort et al., 2009; Fukuma et al., 2012; Gallart-Jonet et al., 2007), and meat (Jeremiah and Gibson, 1997, 2001; Lawrence et al., 2010). In the case of fruit, only a few studies are referred to in the literature for quality preservation, with the majority of these focusing on the ability of the plant to adapt to the cold shock of winter conditions, rather than of supercooling the fruit during storage. Some examples of the application of this technique for the preservation of fruit were cited in James et al. (2009), who reported that apples can be supercooled by as much as 4 °C (Diehl and Wright, 1924), these authors also cited Lucas (1954) who published that studies on grapes, navel oranges and lemons showed that supercooling was possible in these fruits when chilled in air, and in alcohol for lemons. The application of supercooling on tomatoes was reported in a patent application by Cox and Moore (1997) as cited in James et al. (2009).

4. Supercooling process

In the literature, supercooling can be achieved through a diverse array of equipment which includes: near static air (Beaufort et al., 2009; Charoenrein and Preechathammawong, 2010; James et al., 2009) immersion in a water bath with brine or ice slurry (Pineiro et al., 2004; Rodriquez et al., 2005) and immersion in alcohol (Lucas, 1954). Fukuma et al. (2012) examined the effects of two slow chilling regimes on different types of fish meat. They found that when the temperature was reduced by 1.0 °C per day all samples were frozen upon reaching −3.5 °C, whereas when chilled with a 0.5 °C per day reduction, the fish muscle could be taken as low as −5.0 °C in a supercooled state. Nucleation was found to occur in a supercooled product when the meat was subjected to either vibration or a temperature fluctuation. This observation could explain some of the overlap seen in published work on supercooling/superchilling where different outcomes were reported at the same storage temperatures. Cox and Moore (1997) stated that a very rapid temperature decrease is required in order to create the supercooled state in a food, though a rapid temperature drop would not be associated with near static air or low air flow as used in these other works. In contrast to this statement by Cox and Moore (1997), it is more likely that superchilling would be induced through rapid chilling rather than supercooling, as shown by numerous workers in the field of superchilling.

The level of the supercooling achieved has been tested on a variety of foodstuffs such as vegetables, fish and meat. The degree of supercooling achieved (amount of freezing point depression) is highly food sensitive and related to the type of food and its constituents (Gabas et al., 2003). The degree of freezing point depression increases as solute concentration increases (Goral and Khaza, 2002). Sanz et al., reported that meat froze at between −0.6 to −1.6 °C, (1999), James et al. (1983) and Small et al. (2011) reported a freezing point of −1.5 °C and – Lowry and Gill (1984) a freezing point of −2 °C. In fish the range was reported to be −0.6 to −2.0 °C by Chen and Pan (1997) and Magnussen et al. (2008) and −1.0 to −2.2 °C by Silvertsvtig et al. (2002), whereas in other foods a range of −0.5 to −1.1 °C was reported in milk by Beavers et al. (2003) and Boonsupthip and Heldman (2007). Due to the intra and inter species variation in composition, freezing points (based on water and fat contents) will vary slightly for each experiment. Farouk et al. (2013) found that the freezing point of beef muscle was related to the pH of the muscle, with higher pH giving a higher freezing point temperature and lower than normal pH a lower temperature. They stated that these differences were due to the interactions of muscle pH to water holding capacity and so to calculate the freezing point for any muscle the pH would need to be known. Therefore supercooling might be achieved at slightly different temperatures in similar food types and so it is not possible to give an exact value of the freezing point to cover all samples within that specie. Because of this natural variation, some authors may report that supercooling occurred while others found superchilling (nucleation) occurred at the same temperature. With this