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Ice Cream Shrinkage: A Problem for the Ice Cream Industry[1]

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ABSTRACT

When ice cream is shipped from one altitude to another, a change in atmospheric pressure can contribute to shrinkage of the product. Although few recent references exist regarding the problem of shrinkage caused by changes in altitude or pressure, several pertinent articles were published in the 1940s and 1950s. Small air cells, heat shock, high overrun, small ice crystals, improper blending of ingredients, and a wide range of temperature changes during storage are some of the causes of shrinkage in ice cream. Factors reported to reduce shrinkage were 1) factors that tended to produce large air cells and large ice crystals, 2) use of caseinate as an ingredient, 3) higher pasteurization temperature, 4) use of corn syrup instead of cane sugar, 5) reduced milk solids and sugar, 6) higher draining temperature, and 7) use of mono- and diglycerides with polysorbate 80.

(**Key words**: shrinkage, ice cream, altitude)

INTRODUCTION

Problems occur when ice cream is shipped from low to high altitudes or vice versa. Shrinkage of ice cream causes a great economic loss to the ice cream manufacturer. Cole in 1940 (5) observed that the changes in atmospheric pressure that occur when ice cream is shipped from one altitude to another might contribute to shrinkage. Atmospheric pressure changes can cause ice cream to either shrink and pull away from the sides of the container or actually push out of the containers. With the advent of NAFTA (North American Free Trade Agreement) and increased emphasis on all international trade, the effect of shipment of frozen dairy desserts to or from high altitudes has become a major problem. Specific and significant problems in shipping these products to Mexico have already been noticed (G. Bentley, 1994, Hygeia Dairies, Harlingen, TX, personal communication; G. A. Muck, 1995, Dean Foods Co., Rockford, IL, personal communication). With the rapid gains in demand for lowfat and nonfat ice creams, the industry needs guidelines to reduce the occurrence of shrinkage or expansion problems in these products. As the type and amount of nonfat solids increase in frozen dairy desserts, there is more uncertainty as to the type of stabilization or emulsification needed to reduce the incidence of shrinkage. If shrinkage and related problems were eliminated or reduced, the potential for sale of frozen dairy desserts to new markets would be even greater.

Regarding the problem of shrinkage caused by altitude or pressure changes, several pertinent articles were published in the 1940s and 1950s (2, 5, 6, 10, 11, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 25, 26, 27, 28).

The freezing process of ice cream involves incorporation of very small air cells (approximately 110 μm) surrounded by a very thin film of water containing various milk solids (1, 3). As ice cream freezes, a network of ice crystals gives rigidity to the product and prevents air cells from rising to the top and escaping (21). This rigidity is very important in relation to shrinkage in ice cream. Ice cream can shrink or expand from 1 to 30% in volume, and shrinkage is greater in larger packages (22). Shrinkage is caused by the escape of air that has been freed by the collapsing air cells (21). There are typically two types of shrinkage: sinking and diffusion. In the former, ice cream sinks in the containers; in the latter, ice cream pulls away from the package and gradually dries out on the surface (15, 21, 23). Sheuring (23) defined shrinkage as the loss of volume in ice cream before any part of the product has been removed from the container. Arbuckle (1) described shrinkage as a special type of weak body and texture defect.

METHODS OF INDUCING SHRINKAGE

Sheuring (23) induced shrinkage by 1) vacuum of 625 mm for 30 min, 2) air pressure at 20 psi for 30

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min, 3) continuous shaking of samples for 30 min, and 4) holding samples for 6 mo in an ice cream cabinet. Hankinson and Dahle (14) studied shrinkage by subjecting ice cream to 625 mm of vacuum at –26.1 to –31.7°C for 4 h. Dubey and White (7, 8, 9) developed a modified procedure for inducing shrinkage or expansion by subjecting ice cream to 200 mm Hg for 24 h at –29°C to simulate the atmospheric pressure of approximately 2000 m above sea level. Those authors (9) also studied the occurrence of swelling and shrinkage in ice cream that had been shipped in an insulated container at –20 ± 5°C from low altitude (approximately 61 m above sea level) to high altitude (approximately 1676 m above sea level) and vice versa. The ice cream swelled when shipped from low altitude to high altitude and shrank when shipped from high altitude to low altitude (approximately 5 to 10% of volume). The ice cream volume did not come back to the original size during the shrinkage or expansion process, the ice cream but pulled away from the sides of the container when shipped to a low altitude.

METHODS OF SHRINKAGE MEASUREMENT

Shrinkage (i.e., volume loss) has been measured by addition of enough ice water to fill the space lost by shrinkage of ice cream (6, 22, 23). Hankinson and Dahle (14) determined the amount of shrinkage in ice cream by two methods. The first method measured the distance of ice cream from the top and side of the container and recorded it in millimeters. The second method measured the volume loss by pouring ice water into shrunken ice cream cartons. Dubey and White (7, 8, 9) modified a measurement (4) whereby vacuum-induced shrinkage and expansion was determined by submerging ice cream into a volume displacement chamber (Figure 1). Volume displacement was measured by slightly tempering the samples for 10 min at 25°C, followed by submerging and pushing the cartons by pressing with a plunger in a volume displacement chamber (4) that contained 50% diluted antifreeze solution at –29°C. To determine the net volume displaced by the ice cream, the volumes displaced by the plunger and the ice cream cartons were subtracted from the total volume displaced by the ice cream while the carton without its lid along with the plunger was held at the bottom of the volume displacement chamber.

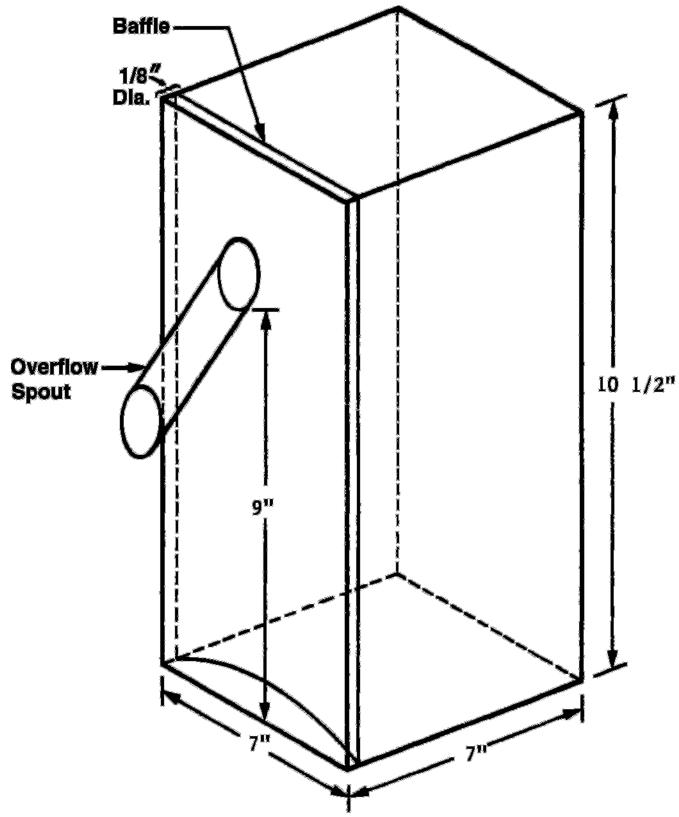

Figure 1. Vessel for volume displacement measurement of ice cream (4).

MECHANISM OF SHRINKAGE OCCURRENCE

The mechanism for explaining the cause of shrinkage and expansion is not clearly understood and may have inhibited scientists from conducting further research since the 1950s. One theory for explaining shrinkage (15) involved application of forces within susceptible ice cream, which creates pressures on the air cell that can lead to its rupture. Forces that are thought to be important are gravity, pressure changes within the air cell caused by temperature changes, changes in atmospheric pressure, and pressure resulting from ice changing to water during storage. A force opposing shrinkage is the bond between ice cream and the container. If the bond is strong, as in the case of tin or paraffin paper containers, ice cream would tend to resist shrinkage despite favorable forces for air cell rupture.

Pressure within an air cell is inversely proportional to its diameter and directly proportional to the temperature. If ice cream is warmed, pressure inside the air cell should increase (14), but does not happen when ice cream is produced and consumed without shipment. The volume of ice cream primarily depends on retention of the entrapped air (14). Increase in pressure inside the ice cream package caused by pressure changes due to shipment of ice cream to a higher altitude, may burst the air cell and permit air to escape and cause shrinkage (22).

FACTORS INFLUENCING SHRINKAGE

Factors that reportedly influence the extent of shrinkage are summarized in Table 1. The following are some of the important factors.

Factors That Increase Ice Cream Shrinkage

Paper or cardboard containers. Shrinkage was greater for ice cream in unwaxed paper or cardboard containers than for ice cream in waxed containers (6, 10, 21, 27). Primarily, containers serve as a packaging material to hold ice cream. However, these authors (6, 10, 27) presumed that the primary function of the container was to prevent the escape of air. According to Hankinson and Dahle (14), containers may play an important role in controlling shrinkage by affecting the strength of the adhesive force or the bond between the ice cream and the container wall. The amount of shrinkage was greater when ice cream was packaged in larger containers (G. A. Muck, 1995, Dean Foods Co., Rockford, IL, personal communication).

Ice cream packaged in paper containers loses weight during extended storage periods as a result of loss of moisture. This loss could be caused, in part, by moisture passage through pores, seams, and unsealed closures of containers or to absorption of moisture by the packaging material with subsequent release of the moisture to the atmosphere (20). Ramsey et al. (21) reported that increased ice cream surface or the porosity of the container wall may have a frequent interchange of air, which allows air to diffuse through the walls of the container, thereby causing a collapse of cell structure leading to the ice cream shrinkage.

Dry ice. The use of dry ice in ice cream trucks and cabinets could be one of the factors affecting ice cream shrinkage (5, 20). It was hypothesized that carbon dioxide from the dry ice was absorbed through the walls of paper cartons or cans directly into the ice cream. Carbon dioxide could have caused pH changes in the ice cream and destabilization of the protein to cause the collapse of air cell structure (20).

Overrun. Generally, shrinkage occurs more readily in ice creams made with a higher overrun, suggesting that the incorporation of more air cells per unit of volume decreases the density of ice cream. Thus, a smaller force might rupture the air cells and permit the collapse of the ice cream structure (15). It is important for the ice cream industry to keep overrun up to 80% or below if the product is to be shipped to or from high altitude (7, 8, 9). Sheuring (22) and Erb (10) suggested that shrinkage in ice cream with less than 85% overrun could be minimized unless extreme conditions prevailed that might influence the shrinkage to occur. This result may be related to the

TABLE 1. Factors affecting shrinkage in ice cream.

Factors	Shrinkage	Reference
Paper or cardboard containers	Increase	(1, 6, 10, 11, 15, 20)
Dry ice	Increase	(1, 5, 6, 10, 11, 21)
Stabilizers	No effect	(2, 6, 8, 21, 23)
Stabilizers	Decrease	(8)
Emulsifiers	Increase	(6, 11, 22, 26)
Emulsifiers	Decrease	(7, 9)
Sugar	Increase	(6, 10, 11, 23)
High overrun	Increase	(1, 10, 15, 21)
Temperature fluctuation	Increase	(6, 10, 16, 21)
Whey proteins	Decrease	(11, 18, 27)
High butter fat	Increase	(21, 22, 23)
Corn syrup	Decrease	(6, 15, 21)
Egg solids	Increase	(6, 11, 21)
High total solids	Increase	(17, 22, 27)
High homogenization pressure	Increase	(6, 10, 23)
Smaller air cells and ice crystals	Increase	(1, 21, 24)
Heat shock	Increase	(21, 23, 24)
Free fatty acids	Increase	(6, 22)
Neutralization of high acid mixes	Increase	(1, 22)
High pasteurization temperature	Decrease	(6, 11)
Freezing too hard and too soft	Increase	(21, 22)
Aging of mix	Decrease	(22)
Loss of moisture due to storage	No effect	(23)
Caseinates or sodium caseinates	Decrease	(11)

fact that ice cream at higher overrun (more than 85%) contained greater amounts of air cell pockets, resulting in a less rigid, weaker body (15). Higher overrun produces ice cream with a weaker air cell structure, which causes collapse, escape of air, and, consequently, shrinkage of ice cream (21). If ice cream is packaged in an unwaxed paper cardboard container, shrinkage problem with high overrun ice cream could even be greater.

Air cells and ice crystals. Fine air cells cause ice cream to shrink more readily than large air cells. Interestingly, this factor is normally associated with improving the textural properties of ice cream. Sommer (24) indicated that escape of air could be involved in shrinkage of ice cream. Ice cream with smaller air cells would tend to shrink more than that with larger air cells because of the greater internal air pressure involved in the former case. According to Sheuring (22), the size and number of the air cells and ice crystals is important in contributing rigid structure to the ice cream, either by preventing air cells from rupturing or by maintaining the air distribution in the cells. Ice cream containing a large number of small ice crystals is not as rigid and will probably shrink more than ice cream containing large ice crystals.

Temperature fluctuation and heat shock. Hankinson and Dahle (14) observed spontaneous shrinkage more frequently when ice cream was hardened at –12 to –17.7°C than samples stored at –23 to –32°C. Vacuum-treated ice cream was resistant to shrinkage as long as ice cream was maintained at temperatures below –26°C. Ramsey et al. (21) suggested that ice cream should be hardened at –23.3 to –29°C. At –29°C, ice cream is more rigid and would be more resistant to shrinkage (1, 3, 14, 21).

Temperatures should occasionally be recorded in several locations throughout the hardening room to ensure temperature uniformity. Ice cream should not be stacked too close to the ceiling of the hardening room where the air does not circulate adequately, resulting in higher temperatures (21). Temperature of the refrigerated truck must be constantly recorded also so that the ice cream can be maintained at uniform temperature throughout the loading and shipping process.

Improper hardening of ice cream should be avoided by allowing every particle of the ice cream to become hard before it is taken out of the hardening room for shipping (21). If the center of ice cream is not hardened properly, the ice cream may shrink or expand while being transported to a different altitude. Subjecting ice cream to heat shock should be avoided. In general, the greater the heat shock, the greater is the amount of shrinkage (6, 23).

Freezing conditions. According to Ramsey et al. (21), shrinkage in ice cream is caused largely by the destabilization effect of freezing on the colloidal suspension of protein surrounding each air cell. Freezing dehydrates the proteins by removing water and precipitates them by increasing mineral salts. More shrinkage is evident when ice cream is frozen too hard and too dry because of smaller ice crystals and finer air cells (21).

Effect of mix processing conditions. Two-stage homogenization pressure of ice cream mixes (3000 psi first valve and 1000 psi second valve) resulted in more shrinkage than with single-stage homogenization except when the pressure applied to the second-stage valve approached the pressure on the first-stage valve. In addition, proteolysis in the mix after pasteurization was more likely to cause shrinkage than proteolysis to the same degree before pasteurization. According to Sheuring (22), neutralization of high acid mixes with either sodium bicarbonate or magnesium carbonate increased the amount of shrinkage over that observed with low acid mixes to which no neutralizing agents had been added.

Effect of ingredients. Sheuring (23) observed that, as fat content of ice cream increased, surface tension decreased, and the tendency for shrinkage increased. Hankinson and Dahle (15), however, reported that variations in fat content from 10 to 16% had little if any effect on shrinkage. Increased concentration of milk solids-not-fat increased surface tension but also increased the tendency to shrink. Sheuring (23) reported no indication that loss of moisture was a factor affecting shrinkage, but dextrose did induce shrinkage. Because sugars affect the viscosity of the unfrozen mass, high sugar concentrations are conducive to shrinkage. Also, high levels of corn sugar or corn syrup cause shrinkage. Too much sugar tends to depress the freezing point (1, 3, 24), which produces a softer ice cream that would be conducive to shrinkage (6, 11, 23).

Freezing affects protein stability and fat emulsion (21). Fat globules in ice cream are dispersed in the colloidal-water interface. The greater the number and size of fat globules, the greater is the impact of reduced interfacial tension. This reduction tends to enhance the collapse of the proteinaceous air cell wall, allowing air to escape and, hence, resulting in greater shrinkage (23). Factors that tend to destabilize the proteins on the air-cell surface may also tend to cause air cell collapse and shrinkage. Factors that favor protein destabilization are enzymes, high heat treatment of milk solids, low freezing temperatures, high acidity, disturbed salt balance, and high homogenization pressures (21, 22). According to Trautman and Nickerson (28), a decrease in the globulin content of ice cream increased the tendency for ice cream shrinkage.

Factors That Decrease Ice Cream Shrinkage

Corn syrup. Dahle et al. (6) reported that, when corn syrup was substituted for 30% of cane sugar, less shrinkage occurred than when cane sugar was used alone.

High pasteurization temperature. High pasteurization temperatures, especially 87.8°C for 20 min, were very effective in reducing shrinkage (11).

Aging of mix. Sheuring (22) reported that reconstituting a dehydrated mix and freezing immediately resulted in more shrinkage than when reconstituted mixes were aged overnight prior to freezing. Freezing of unaged mixes increased the amount of shrinkage; however, no advantage was observed in aging mixes longer than 48 h. Frazeur and Dahle (11) stated that holding mix at 4.4°C for 48 to 72 h increased shrinkage.

Whey proteins. Goff et al. (13) reported on the influence of various whey protein isolates in milk on the emulsion stability of ice cream. They indicated that 95% whey protein isolate contributed desirable properties, such as improved emulsion stability and fat destabilization, to an ice cream mix and also to the frozen product. Thompson et al. (25) found that the use of succinylated whey protein concentrate increased viscosity and resistance to melting and reduced freezing time and overrun. These effects (13, 25) were apparently related to improved functionality of whey proteins, which eventually would have contributed to minimizing shrinkage caused by higher overrun or smaller air cells. The addition of unaltered whey proteins to ice cream mixes reduced shrinkage considerably, probably by enhancing air cell binding and water entrapment (18). It was reported (11) that the addition of concentrated whey, equivalent to 10% of the serum solids of the mix, reduced the amount of shrinkage.

Emulsifiers and stabilizers. Stabilizers probably affect the manner in which the air is incorporated, which in turn affects the amount of shrinkage (15). Goff and Jordan (12) suggested that, based on the ability to lower interfacial tension, emulsifiers control adsorption of protein to fat globule surface, which could cause fat in lowfat ice cream to become more susceptible to coalescence. Results of these studies (12, 15) were related to controlling shrinkage in nonfat ice cream (7, 8).

Conflicting results have been reported by previous researchers (2, 6, 8, 11, 15, 21, 22, 23, 26) regarding the use of stabilizers and emulsifiers to reduce or eliminate shrinkage and expansion of ice cream. Sheuring (23) made the following observation based on 25 mix preparations: 1) emulsifiers lowered the surface tension of mixes, 2) the type of emulsifier was more important in reducing the surface tension of mixes than the amount used, 3) emulsifiers tended to reduce the protein stability of mixes, and 4) the use of emulsifiers in mixes increased shrinkage incidence. Recent studies indicated that mono- and diglycerides with polysorbate 80, along with stabilizers such as a combination of locust bean gum, guar gum, and carrageenan, could be used to minimize shrinkage problems in ice cream (7, 8, 9).

CONCLUSIONS

Shrinkage in ice cream is a serious problem, and an early solution is necessary to prevent ice cream companies from losing national and international markets. With increased international trade and an efficient transportation system, shipment of ice cream products has become more prevalent. Shrinkage caused by changes in altitude is still a problem for the ice cream industry. Different treatments produce various degrees of volume changes, depending on conditions (Table 1). Based on a review of the literature, it may be concluded that ice cream should be allowed to harden at –29°C for minimum of 72 h before shipment to the sales outlets. Also, it is critical to maintain the temperature of the shipment cabinet between –25 to –30°C while the product is being transported to or from high altitude. The use of emulsifier such as mono- and diglycerides with polysorbate 80, along with stabilizers such as a combination of locust bean gum, guar gum, and carrageenan, could be one of the solutions to the problem.

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