THARP & YOUNG ON ICE CREAM

An Encyclopedic Guide to Ice Cream Science and Technology

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To past, present and future ice cream scientists and technologists.
To those using this Guide, be focused and serious, and have fun along the way!

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FOREWORD

Ice cream and other frozen desserts have a universal appeal to children of all ages. There has seldom been an occasion when I have talked about ice cream and not seen joy and smiles on the faces of the audience. These talks are generally followed by numerous questions about the science, history and mythology of these products. The number of technical personnel working in the area of commercial ice cream manufacture is relatively small and the need for technical guidance becomes relatively great. In this small circle it has been my privilege to get to know and collaborate with Drs. Bruce Tharp and L. Steven Young over the past 30 years or so. Therefore, when they asked me to write a Foreword for *Tharp & Young on Ice Cream: An Encyclopedic Guide to Ice Cream Science and Technology,* I was honored and happy to oblige. Besides the authors' own long careers in the dairy industry, their interest in the subject matter of this publication was inspired by their respective fathers, who also were dairy technologists. I may be the only one in the industry who knew all four, the two fathers and both their sons. Such family traditions, combined with their own experiences, provide a unique vantage point to address the complexity of ice cream science and technology.

Given their vast knowledge and collective experiences of about a century with ice cream and frozen desserts, the authors set out to convey their encyclopedic knowledge of the subject matter for anyone interested in the technical aspects of frozen desserts. The authors approach this task by presenting an alphabetical classification of terms and jargon used in the industry with a goal of providing the reader with practical implications of the terms used in the frozen dessert industry. This *Guide* is not only a source of technical explanations but also offers ideas for new products and processes supported by insightful tables and illustrations and essays on selected "hot topics." Drs. Tharp and Young have a unique way of bridging the gaps and connecting the dots among science, technology and commercial reality.

As I had expected, this *Guide* is comprehensive in its coverage, and key terms are fully discussed to clarify complex technical ideas and their applications. It is an essential reference for personnel in the ice cream industry. There is no other book of this kind in the current marketplace. It is truly a labor of love for the authors to take this exhaustive approach to catalog and explain terms. As a dictionary is essential to clarify the meaning and origin of words, this *Guide* is a dictionary for the ice cream industry, with deeper technology-related insights and experiences included. I hope that readers enjoy referring to this book as much as I enjoyed perusing it. I salute these professionals for their contributions in the form of this book.

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PREFACE

The purpose of *Tharp & Young on Ice Cream: An Encyclopedic Guide to Ice Cream Science & Technology* is to interpret Mother Nature's rules, the naturally occurring rules of chemistry and physics, and to provide a practical guide to ice cream making consistent with those rules. The *Guide* is not meant to be a definitive scientific reference. We humans created and make ice cream, and it's up to us to continue to learn, develop and understand how to make quality products (with accuracy and precision) consistently, if enjoyment of ice cream is to continue. How to do this requires translation of the scientific rules-of-the-road into useful guidelines, approaches and technologies. This is our goal—and the focus of the *Guide*.

We are proud to present the *Guide* as a culmination of more than 100 years of combined industrial, academic and personal experience. From the scientific and technical points of view, we report findings drawn from the cumulative knowledge generated by over 150 years of scientific investigation that followed the advent of the modern age of ice cream manufacturing and by the observations of those who have applied the results of those investigations to the ongoing understanding and evolution of ice cream manufacturing. To all this, we add knowledge based on our own empirical observations made over the course of our careers to provide further practical insights and direction. This has included, since 1997, dialogue with the attendees of our worldwide presentation of the "Tharp & Young On Ice Cream" series of technical short courses (www.onicecream.com). We have learned much from the exchange of information with the attendees at these courses, as they represent, to date, over 500 companies from over 100 countries making and selling ice cream in one form or another.

It is important to understand that the guiding principles used to formulate and make all frozen desserts are the same. So, we use the term "ice cream" to refer generically to all frozen desserts (dairy-based or otherwise), to which all scientific principles apply. We also understand that practical elements of making ice cream continue to evolve, and we suspect new scientific learning, technologies, approaches and products are being developed as we write.

Thus, we have concentrated on the basic and theoretical to create understanding that can be put into practice. We acknowledge simplifying the science to increase understanding and for being technically opinionated while doing so, but that's the nature of writing a book such as this. Opinion, after all, is often based on the application of Mother Nature's rules with a pinch of experience added.

As with all evolving science and technology, change happens, can occur at any time, and is critical to ongoing learning. Thus, we have added new concepts and approaches conceived during the writing of this *Guide*, which, though not yet fully vetted or completely understood, are, nonetheless, critically important technical considerations. If we missed something along the way, get in touch with us. Just as ice cream making continues to grow through new discoveries and learning, so too, with the help of astute readers, will this *Guide*.

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ACKNOWLEDGEMENTS

We thank those whose work is the source of the scientific information that is an important part of the Guide. As appropriate, we formally acknowledge specific elements of these contributions throughout the Guide.

We are grateful to the many individuals who contributed to our efforts. This includes our combined network of professional colleagues who provided illustrative material, advice, counsel, and other input. Dr. Arun Kilara, former Director of the Penn State Ice Cream Short Course, was helpful through his contribution to the selection of the topics covered. He provides the Foreword to this text.

Special thanks go to DEStech Publishing Company, in particular Dr. Joseph Eckenrode, for guidance and patience as the manuscript moved from deadline to deadline.

We also thank the editors of *Dairy Foods* magazine, with whom we have been close literary partners across the years, for allowing us to use (with select updates and corrections) our quarterly columns on new and novel ice cream technologies, approaches and products.

Finally, and most importantly, we acknowledge, with profound gratitude, the contributions of our families, whose encouragement and support from concept to completion has been indispensable to our efforts. That must also include homage to the role of our fathers—both dairy industry pioneers—in inspiring us to follow the careers that made this book possible.

INTRODUCTION

Among the foods that nourish us and give us pleasure, ice cream, along with its many frozen dessert variations, is one of the most enjoyable. It seems to be the simplest of comestibles. However, ice cream is also one of the most intricate, complex and technically challenging food products made. Its complexity is compounded by the fact that it is the only food of which we are aware that is conceived and engineered with the full intention of being consumed frozen.

Given this, insight into the intricacies of ice cream begins with the need to develop a composition that takes into account the multiple, interacting, and sometimes counterintuitive laws of chemistry and physics that apply to making ice cream. Anyone developing an ice cream composition must also consider the requirements of production, marketing, sales, distribution and, certainly, the needs and expectations of the consumer. The regulatory environments into which products are marketed and sold also affect much of concept development, compositional decision-making, and, in turn, selection of the most appropriate science and technology for making ice cream. Necessary inputs influencing mix composition are summarized in Figure 1. Many of the concepts explained in this book are subcategories of these inputs. Responsibility for balancing all these inputs and for deciding compositional priorities, final composition, list of acceptable ingredients to use, etc., is distributed in a number of ways, depending on the product and the manufacturer. The information included in the terms defined in the main section of the *Guide* is designed to assist in understanding and coordinating the complex ideas underlying the creation of a sound ice cream product.

Composition and production guidelines are presented not only for ice cream but also for sherbet, sorbet, water ice, novelties and gelato, as well as frozen yogurts, parevine and many other specialty products. Indeed, numerous suggestions and ideas are given for the development of entirely new and non-standard frozen desserts.

After a decision on what is to be made comes production, a complex series of processes illustrated in Figures 2 and 3. The equipment used in each individual step in making ice cream varies by design, capability and capacity, adding further challenges to the delivery of an acceptable product to the consumer. The present volume contains photographs and schematics of major components of ice cream manufacturing equipment.

Production begins with the generation of a formula that will deliver the composition that has been developed. The initial step entails the selection of dairy ingredients (milk, cream, or their analogues) from the supply available, with milk being one of nature's most variable and complex edibles. Milk's components and their chemistry are explained in detail. To milk and other dairy ingredients are added materials selected from a wide variety

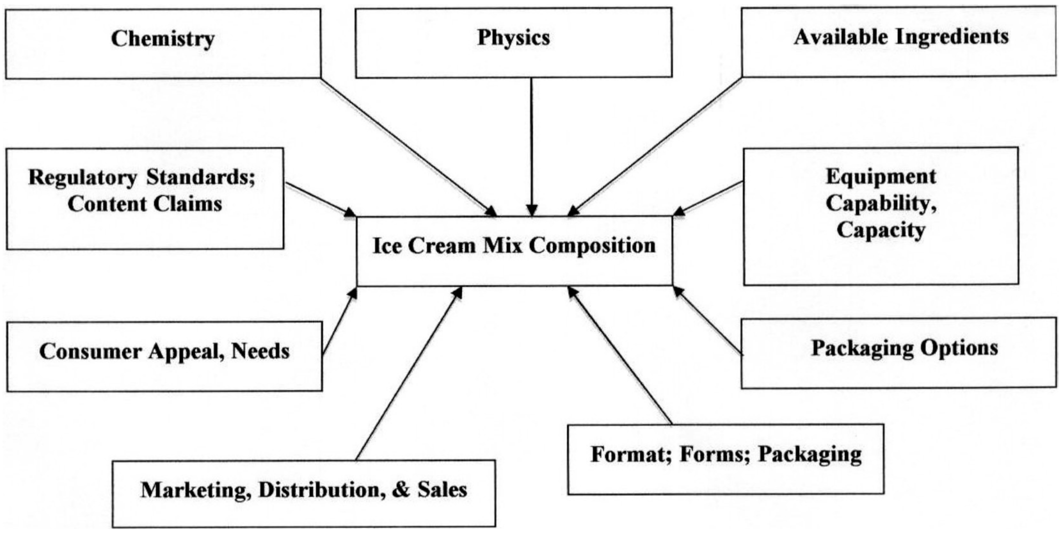

Figure 1. Inputs to mix composition development.

of other complicated and technically novel food ingredients (sweeteners, bulking agents, stabilizers, and emulsifiers), whose functionality in ice cream is explained in depth. The finished blend of ingredients, known as the mix, then undergoes a complex series of processing steps, as illustrated in Figures 2 and 3. Those steps include the application of high temperatures and pressures and the further complications of freezing and whipping. The nuances and subtleties of the processing steps, e.g., freezing, are not only clarified but also quantified in numerous tables and charts in the text.

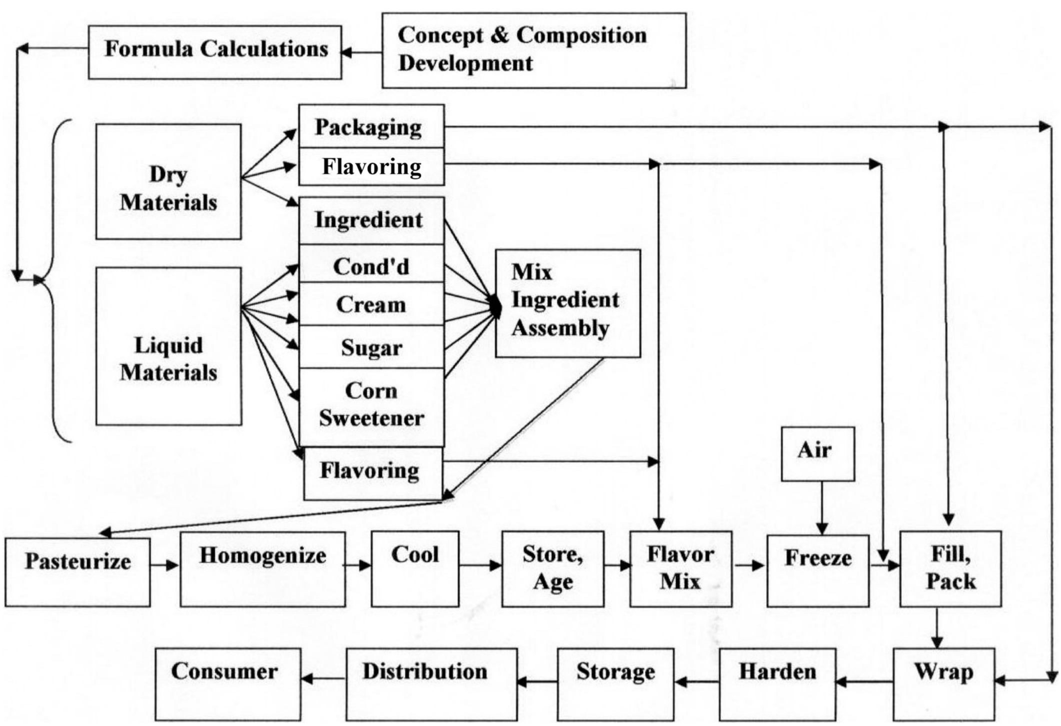

Figure 2. Basic ice cream process flow: concept to consumer.

Superimposed on the process is a dazzling variety of flavors, flavorings, and colors that characterize each product. Variety continues with the availability of a wide range of packaging forms. These go from the bulk pack used for dipping to containers for direct consumer sale, which include differing package sizes and hand-held novelty options that can be direct-filled, extruded, or molded. Beyond these are soft serve and milk shake formats, as well as novelties of all kinds.

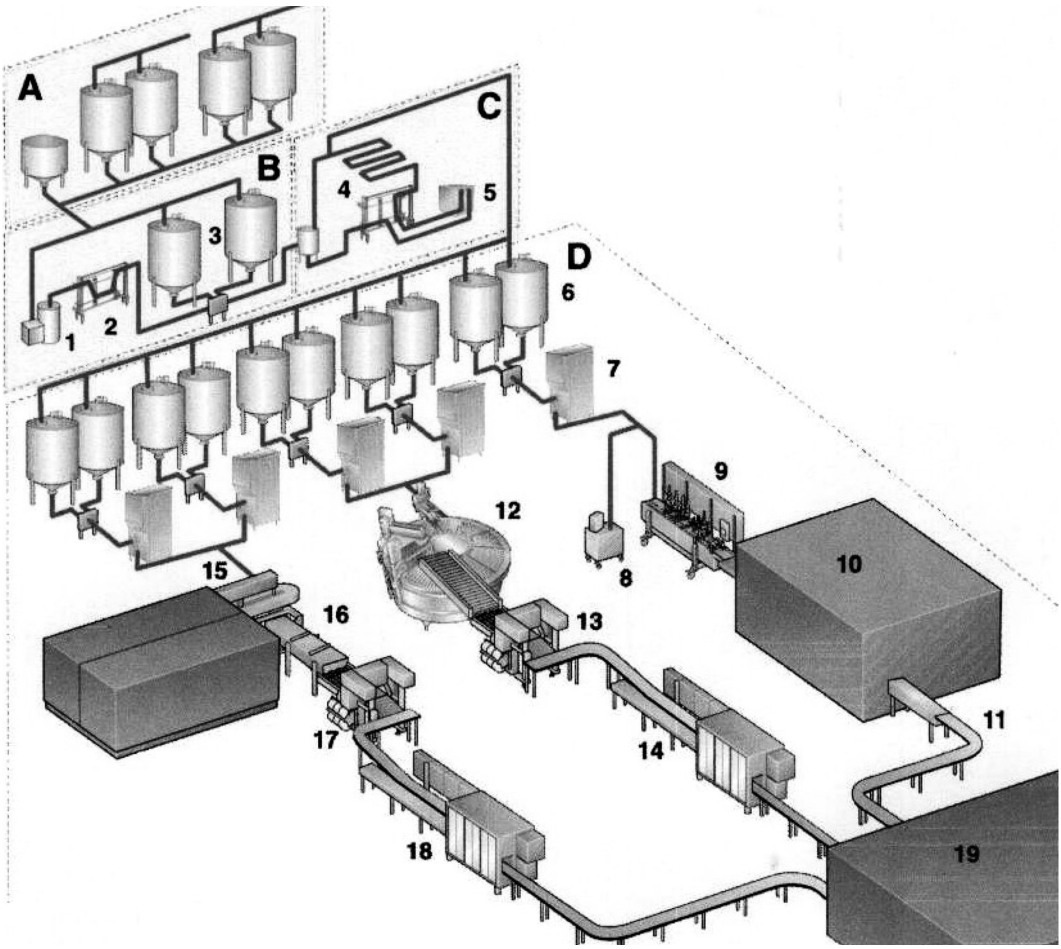

Figure 3. Large ice cream plant for manufacturing packaged ice cream and novelties (used with permission, from *Tetra Pak Dairy Processing Handbook*, 2003).

A. Raw material storage
B. Mix assembly
   1. Mixing unit
   2. Plate heat exchanger
   3. Mix tanks for continuous mix making
C. Pasteurization, homogenization, fat/oil standardization
   4. Plate heat exchanger
   5. Homogenizer
D. Ice cream manufacturing
   6. Aging tanks
   7. Continuous freezers
   8. Ingredient feeder
   9. Cup/cone or carton filler
   10. Hardening tunnel
   11. Carton line
   12. Bar freezer
   13. Wrapping unit
   14. Cartoner
   15. Tray tunnel extruder
   16. Transfer enrober
   17. Wrapping unit
   18. Cartoner
   19. Cold storage

Beyond processing, additional technical and non-technical nuances related to distribution, marketing, sales, and point of consumption considerations are critical as well. Each finished product must have sustainable and defensible points of difference vs. its competing set, some of which may be products of the same brand. There is also the need to consider the regulatory environment for compatibility or non-conformance. General, ingredient and nutrition labeling all enter the equation. Finally, economics plays the ultimate role in delivering what is promised at a profitable price-point. Because successful ice cream and frozen dessert production requires consideration of multiple factors beyond actual processing, the *Guide* offers extensive information on cost calculations, product testing, and legal regulations.

The definitions and essays that follow are intended to provide understanding of, and guidance in, devising a successful product formulation and implementing the ice-cream making process, while at the same time applying operational procedures, scientific laws and sound marketing and legal principles—with creative ideas for new kinds of ice cream and frozen desserts.

HOW TO USE *"THARP & YOUNG ON ICE CREAM: AN ENCYCLOPEDIC GUIDE TO ICE CREAM SCIENCE AND TECHNOLOGY"*

"Tharp & Young on Ice Cream: An Encyclopedic Guide to Ice Cream Science and Technology" is meant to be both a reference manual and a book to be read cover to cover. Because science and technology rarely exist in a vacuum or without context, a lot of back and forth discussion must proceed before the practical application of multiple inputs can be fully appreciated. Toward this end, we have crafted a discussion of ice cream science using primary topics presented alphabetically as simple definitions, which are supplemented and clarified by more extensive essays. Readers are encouraged to pursue cross-references to gain a fuller definition of many terms, along with important supporting data.

Cross-referencing to entries is accomplished with five conventions:

1) Terms defined by an entry appear in **boldface** type.
2) A word that is used within an entry and is itself a separate entry is distinguished by small capital letters. For example, "Ice cream may include WHEY, which is derived from cheese production."
3) A word that is not used in an entry but has been added within a definition and is itself a separate entry will be italicized, e.g., (See also *whey.*).
4) In entries where the sole "definition" is a reference to another entry, the second entry appears in regular type. For example,

   Acid whey
   See whey.

5) At the end of some entries and paragraphs, further entries are added as part of a separate sentence after the word "See." These further entries also appear in regular type. For example, "See lactase, whey, whey solids."

The Appendix contains descriptive essays adapted from quarterly columns for *Dairy Foods* magazine. These provide supplemental insights to appropriate primary entries. The Appendix essays, which are separately titled, stand alone, i.e., they have no references back to primary entries, since all technical terms and concepts used in them have also been used in entries from the main body of the book. However, within and at the end of entries in the main body of the book, references have been added to direct the reader to an appropriate Appendix essay. The convention for doing this is: "See Appendix essay, title of essay."

The term "ice cream" is used both literally and generically throughout. In its literal use it refers to a frozen product meeting the regulatory elements required for the use of the term. Generically, it is used when appropriate in the context of the relevance of material discussed to the broad range of frozen dessert products, i.e., soft serve, direct-draw milk shake, frozen yogurt, sherbet, sorbet, water ice, frozen dairy desserts, non-dairy frozen desserts, and the like. However, those specific terms referring to a product category are used whenever the information presented is specifically relevant to a given category.

In most instances we provide both English (e.g., USA gallons, degrees Fahrenheit) and metric (e.g., liters, degrees Celsius) units. However, for references to currency when discussing economics etc., US dollars (USD) are used exclusively.

In some instances, where alternative terms exist for a certain topic, discussion of the topic will appear for only one of the terms. The others will be characterized with a directional reference to further coverage. (See #4 above.)

We have included new terms that we have introduced to the industry (e.g., "hybrid products," "true sugar-free ice cream," "flaky," etc.). Such terms are not identified as new, but are re-defined as critical to understanding the growing science supporting their use. In some instances we do introduce new terms or approaches (e.g., "water control index") that may not yet be fully vetted or understood, but are critical in their own way toward understanding, formulating and making quality ice cream. When they appear, we identify these concepts as new.

There is no index. The text itself is an index *per se*, given the cross-referencing done in virtually all entries.

In all cases the wording in the book is our own. We are grateful to the many companies and individuals who have allowed us to use materials they have generated. We have identified those sources as appropriate.

Tables and figures are referenced by an alphanumeric designation using the alphabetic placement of the first letter of all entries of a given letter and a sequential number. For example, Figure M-6 is the sixth figure under the entries beginning with the letter "M." Likewise, Table M-6 is the sixth table within the same alphabetized grouping.

Regulatory considerations (e.g., standards of identity, good manufacturing practice, labeling, etc.) related to ice cream and related products differ from country to country and may differ among states or regions within any given nation. Further, changes in regulations occur constantly and it is simply not possible to cover all regulatory considerations under all situations at any given point in time. We use USA standards of identity and other USA regulatory standards to demonstrate how standards, general labeling, nutrition labeling, and other regulatory considerations can and should be used to achieve any given finished product objective.

THARP & YOUNG ON ICE CREAM

An Encyclopedic Guide to Ice Cream Science and Technology

A

Absorbed flavor

Absorbed flavors are FLAVOR elements associated with aromatic compounds that are infused from the atmosphere in which ice cream is stored. Heavy concentrations of such compounds in the atmosphere and/or loosely sealed packaging can make this possible. This scenario was formerly a more important consideration than is now the case. That is reflected by the presence of the term "storage" in the list of descriptors on the official ice cream score card. When added to the list, "storage" was intended to refer to the presence of absorbed flavor contaminants. As ice cream packaging became more tightly sealed and impervious to the absorption of gases, the term has fallen into disuse because of its lack of relevance to current conditions and its nebulous nature. It is now rare that ice cream is contaminated by absorption from the atmosphere.

Acacia gum

Acacia gum (gum arabic) is a natural gum which is a mixture of saccharides and glycoproteins derived from an acacia tree exudate. It has a low viscosity in water and, therefore, limited water immobilization functionality. It is, therefore, rarely used as a STABILIZER in ice cream. However, under the influence of FREEZE CONCENTRATION, its functionality (e.g., managing the VISCOSITY of the unfrozen portion of the mix at extremely high per cent of water frozen) in ice cream may be of value. Acacia gum is widely used in flavoring materials at relatively high levels because of its excellent ability to stabilize flavor oil emulsions. This emulsification capability may be functional in ice cream when considering specific processing systems, such as LOW-TEMPERATURE EXTRUSION. Acacia gum is also known as gum arabic and, in purified form, as arabinogalactan. See Appendix essay, Low viscosity polysaccharides.

Accretion

Accretion in ice cream refers to a condition in which ice crystal growth causes crystals to grow together, creating sudden and dramatic growth in average ice crystal size. See crystallization, heat shock.

Acid/fermented flavor

Acid flavor, sometimes associated with a fermented flavor, is caused by the activity of LACTIC ACID BACTERIA, i.e., bacteria whose metabolism is dominated by the derivation of energy from the conversion of lactose to lactic acid. This is differentiated from acid flavor alone, which may be found in products where specific acids (ACIDULANTS) are added on purpose to enhance a specific flavor profile (e.g., citric acid to enhance citrus flavor). Examples of products to which acid may be added include SHERBET, SORBET, and WATER ICE. By-products of lactic acid fermentation include lactic acid and small but potent levels of other compounds whose volatility produces a flavor profile broadly described as a fermented character. The nature of that flavor is similar to that of the flavor of such cultured dairy products as cottage cheese, sour cream and buttermilk. Ordinarily, the presence of those otherwise desirable flavor characteristics in ice cream is considered to be a defect. However, in frozen desserts such as frozen yogurt and cheesecake-flavored products the acid/fermented flavor is a desirable characteristic that more or less dominates the flavor profile.

Previously, when the conditions of producing and handling milk were favorable to the growth of lactic acid organisms, the lactic acid fermentation flavor profile was a very common cause of dairy ingredient spoilage. The acid/fermented character is relatively uncommon now in most parts of the world. That is the case where milk and other dairy products are produced, gathered and stored under conditions that virtually exclude contamination by lactic acid bacteria and favor the development of other organisms. It is rare that a fermented flavor develops in ice cream mix after processing. Rather, it usually results from the use of dairy ingredients in which the flavor has already developed. Therefore, when the fermented character does show up in conventional ice cream, its source can usually be found in one of the dairy ingredients. The investigation of its presence should not overlook dry dairy ingredients, since the defect could have developed in the fluid predecessor of any of the dry dairy ingredients.

Acidulants

Acidulants are ingredients that add acid and may, depending on the buffering capacity of the mix, reduce pH. Some of the more useful acidulants are lactic, malic, and citric acids. Many other similar edible ORGANIC ACIDS can be used. However, each added acid not only contributes acid but also adds a typical flavor or aftertaste that may, or may not, be desirable. Of interest is GLUCONO DELTA-LACTONE (GDL), which produces gluconic acid when added to water. Phosphoric acid is also a recommended acidulant. GDL and phosphoric acid help reduce pH without harshness, bitterness, or lingering flavors and aftertastes. Sometimes "natural" acidification can be achieved through fermentation, as in culturing milk solids to make frozen yogurt. Use of an acidulant to acidify frozen dessert mixes may be advisable or required by law. Frozen desserts with added acid include frozen yogurts, sherbets, sorbets, and water ices.

Acid whey

See whey.

Aftertaste

Aftertaste refers to the perception of flavor that remains after ice cream has been swallowed (or, in the quality assurance SENSORY EVALUATION context, expectorated). During mastication (i.e., chewing), the time, intensity and amount of film of a product coating the mouth and thus exposed to body heat produce vaporization of volatile flavor components. Compounds that have resisted volatilization may result in tastes that linger after mastication. These are aftertastes. In some cases the detection of these components facilitates the precise identification of a particular off-flavor. For example, the flavor contributed by whey solids cannot always be specifically identified early in the sensory evaluation process. However, focusing on the aromas being perceived during the aftertaste period allows the identification of the specific source. Thus, aftertaste is an important part of the sensory evaluation of ice cream products.

Agar

Agar is a seaweed-derived polysaccharide HYDROCOLLOID made up of repeating units of GALACTOSE derived from seaweed. Classically, agar has been widely used in culture media for microbiological work; it has little application in ice cream, where the very firm gel it produces is not desirable. Reconsideration of agar in ice cream may be appropriate under certain application and economic conditions.

Agave nectar

Agave nectar, sometimes referred to as agave syrup, is a natural sweetener with a distinctive flavor. It is extracted from the agave plant. The principal sugars present are FRUCTOSE and DEXTROSE. The proportions vary with the source, but fructose is usually predominant. Some versions of agave nectar resemble the composition of HIGH-FRUCTOSE CORN SYRUP. Sweetness and flavor characteristics vary with the fructose/dextrose ratio. Because of its low glycemic index, it is attractive for use in HEALTH-RESPONSIVE ICE CREAMS.

Agglomeration

See coalescence, fat agglomeration.

Aging

Aging refers to the first few hours of mix storage after processing. It involves holding pasteurized, cooled ice cream mix at temperatures less than 40°F (4.5°C). Aging provides time for the final mix viscosity to be reached due to the development of the full hydration of milk proteins and, in some cases, stabilizers. However, its primary purpose is to allow the fat globules to develop characteristics that will produce the target level of FAT AGGLOMERATION during freezing. That involves two elements. The first is the achievement of equilibrium with respect to the crystallization of fat, a key factor related to fat agglomeration. In addition, the crystallization of milk fat improves the efficiency of the freezing process in the barrel of the ice cream freezer by removing the heat of fusion of the milk fat and also conditions the fat for agglomeration. The time required to condition or crystallize the fat is about two hours.

Aging is also critical for the development of conditions at the surface of individual fat globules that affect the adhesion of the globules when they collide during the high shear applied during the freezing/whipping process. The time needed for that to occur depends upon the nature of the emulsifier system. For unemulsified mixes, or those using PHOSPHOLIPIDS (lecithin) or saturated MONO-DIGLYCERIDES, about four hours is required. For unsaturated monoglycerides, two to three hours of aging is needed. When a significant amount of the emulsifier system is a polysorbate, particularly POLYSORBATE 80, achieving surface equilibrium is virtually instantaneous. This is due to the unusual functionality of polysorbate 80. See fat agglomeration, emulsifiers.

Air bubbles

Air bubbles, sometimes referred to as air cells, refer to the form in which air is entrapped in ice cream. The nature of the air bubbles is a critical element for many key ice cream properties.

Before the ice cream mix enters the freezer barrel, an amount of air appropriate for the target OVERRUN is metered into the mix flow as relatively large bubbles. During the freezing/whipping process the SHEAR applied by the whipping portion of the DASHER reduces the size of the air bubbles and then maintains the uniform distribution of the small bubbles until the ice cream is frozen stiff enough to hold them in place.

The strength of air bubbles is directly related to the nature of the structure that surrounds them and maintains their integrity. That layer, known as the LAMELLA (plural: lamellae), is similar in function to the rubber that holds air in a balloon. It is made up of various components of ice cream that are attracted to the energy differential at the interface between the air and the aqueous unfrozen portion of the ice cream. Managing the strength of the lamellae is the key to maintaining a small air cell size, both during freezing and in the ice cream after packaging. The strength of lamellae is particularly relevant to controlling SHRINKAGE. The stronger the lamellae, the less likely they will be to rupture and allow air to escape, thus reducing the possibility of shrinkage.

It is important that air bubbles in the finished ice cream be as small as possible. Small bubbles provide increased stiffness at the freezer, contribute to the perception of richness/creaminess, and add shape retention. They also help in controlling the growth of ice crystals by reducing the volume of interstices between bubbles (see *crystallization*). The whipping element of the ice cream freezer dasher is designed to be very effective in producing small bubbles. Unfortunately, as is the case with ice crystals (see *crystallization*), scientific laws favor the development of large air bubbles rather than small ones when conditions permit. Thus, the size of bubbles can increase during the freezing/whipping process as the result of collisions between small bubbles and their COALESCENCE into larger ones. That represents a major challenge to the process of delivering rich, creamy ice cream to the consumer and achieving and maintaining overrun. That is particularly the case when the overrun target is high, as is often the case in NON-STANDARDIZED FROZEN DESSERT and FAT-MODIFIED products.

Air bubble size can also increase by a process called disproportionation. That is a phenomenon that can cause the growth of air bubbles after the ice cream leaves the freezer barrel. The air in small air bubbles is more soluble than that in larger bubbles. Therefore, when conditions permit, the air in the smaller bubbles will dissolve into the unfrozen aqueous phase if the air bubble lamella is not strong enough to prevent that from happening. Then, if the VISCOSITY of the unfrozen phase permits, that air will migrate to and be taken up into larger bubbles, increasing their size. That process is analogous to the RIPENING of ice crystals and, like ripening, occurs more extensively at higher temperatures. At higher temperatures, the viscosity of the unfrozen phase decreases, and the air is more likely to migrate out of the small bubbles and become involved in air bubble growth. The disproportionation phenomenon is one of the factors that make it desirable to harden rapidly and store the product at low temperatures during distribution.

Contributors to lamellae strength and therefore to the presence of small air bubbles, include:

- Fat globules, both individual and agglomerates. The agglomerates provide more strength than the individual fat globules; thus, control of the development of FAT AGGLOMERATION is an important element of controlling air bubble size.
- Protein, both casein and whey protein, through a direct orientation at the air bubble surface and indirectly through their effect on the RHEOLOGY of the unfrozen portion (see below).
- Native and added EMULSIFIERS contribute primarily through their influence on fat agglomeration. However, they can also be involved directly through their orientation at the air bubble surface.
- Rheology of the unfrozen portion. FREEZE CONCENTRATION reduces the occurrence of air bubble coalescence by increasing the viscosity of the unfrozen portion of ice cream and/or the development of a gel structure. That occurs by increasing the levels of components involved in controlling WATER MOBILITY, including protein, bulking agents and, most particularly, stabilizers. The gelling effect of MICROCRYSTALLINE CELLULOSE, which occurs even in the absence of freeze concentration, is particularly effective in this regard.
- Pre-aeration. For reasons not completely understood, the application of PRE-

AERATION produces smaller, more stable air bubbles than those formed when whipping occurs only in the barrel of the ice cream freezer.

The strength of lamellae is especially relevant to controlling shrinkage. The stronger the lamellae, the less likely they are to rupture and allow air to escape and cause shrinkage.

Figure A-1 shows an electron photomicrograph of the inner surface of the crater that had been occupied by an air bubble. It clearly shows a substantial presence of fat globules, both individual and agglomerated, at the lamella. Other entities that contribute to lamellar strength, such as proteins and emulsifiers that are attracted to the interface between the air bubble and the unfrozen mix, are too small to be visible in the photograph.

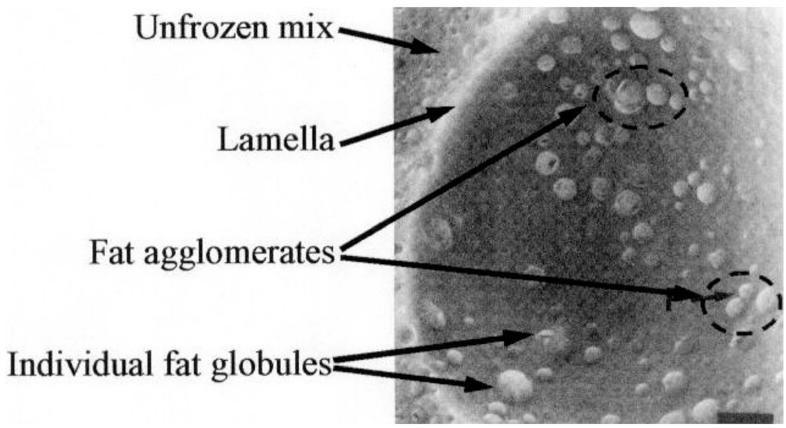

Figure A-1. Scanning electron microscope image of an air bubble in ice cream. From Caldwell, Goff and Stanley, "A low-temperature scanning electron microscopy study of ice cream. I. Techniques and general microstructure." *Food Structure,* Vol. II, 1992.

Air cells

See air bubbles.

Air filter

An air filter is a device on an ice cream PROCESS FREEZER used to purify the air removed from the atmosphere and incorporated into the ice cream as overrun.

Alcohol

An alcohol is an organic compound made up of one or more carbon atoms in which a structure containing an atom of hydrogen is joined to an atom of oxygen. This structure is known as a hydroxyl group (usually expressed as OH). It is attached to one or more of the carbon atoms. In ice cream, alcohols are sometimes used as carriers for flavorings or as SUGAR ALCOHOLS used as alternative sweetening systems.

Alginates

See stabilizers.

Allergens

Allergens are agents, usually proteins, which trigger the release of antibodies, which can result in negative physiological reactions. Allergic reactions differ from food intolerances (e.g., LACTOSE INTOLERANCE) in that food intolerances relate to an inability to digest or utilize a given food or food component, yet do not elicit a true antibody reaction. Allergic reactions range from minor to quite severe. It is always important to determine and control a situation where potential allergens are ingredients in, or can accidentally "contaminate," finished ice cream.

The following list includes about 90% of all known food allergens.

- antibiotics
- peanuts and other nutmeats
- eggs and egg products
- dairy (casein, whey)
- fruit and fruit constituents
- chocolate and cocoa
- fish/shellfish
- soy products (proteins)
- wheat gluten

Other potential allergens exist, and it is critical to stay current, in order to be able to control newer sources that might enter ice cream via a required ingredient, color or flavor or by environmental contamination, such as from other ice creams being made at the same location or on the same equipment.

In terms of allergen control, it is necessary to understand the following factors:

- Location of potential allergen entry into a food: How, when, or where did the specific allergen enter the food? In some instances, allergens may be essential ingredients to make the finished food (e.g., milk, cream, etc., for ice cream).
- Ingredient sourcing: It is important to know how, when, and where potential allergen(s) can enter ice cream via specific ingredients. For example, allergen(s) can enter ice cream via added flavors, flavorings, or INCLUSIONS.
- Product line crossovers: Crossover refers to changeovers from one product to another on the same manufacturing line. Does the presence of an allergen in one product enter or contaminate a second product?
- Management of REWORK (rework "same-to-same"): Rework can be a significant problem. It is always desirable to rework "same-to-same" and not to rework one product with a known allergen (e.g., egg solids) into a second product which does not declare that specific allergen as an ingredient.
- Equipment maintenance: Maintaining and properly sanitizing equipment between product types help to reduce crossover contamination.
- Packaging and labeling: Proper and readily apparent allergen labeling is critical to open and public declaration of the potential presence of a given allergen or allergens. Most allergen problems result in contamination of an ice cream by ingredient(s) containing one or more allergens that are not declared on the label as an ingredient.
- Manufacturing scheduling: It is possible to control or monitor potential allergen contamination by scheduling those products with known allergens (e.g., egg solids) in a way that minimizes or eliminates any chance of allergen contamination in products that are not appropriately labeled.
- Cleaning protocols and scheduling: As with other key elements, a comprehensive and effective sanitation program designed not only to keep ice cream pathogen-free but also allergen-free is required.

Eliminating or reducing potential allergen-related problems has become a major element of all quality management programs. In ice cream, numerous allergens are routinely used (e.g., dairy products, egg products, nutmeats, gluten-containing baked INCLUSIONS, etc.). It is the role of quality management programs to ensure allergens are restricted to the ice creams for which they are intended and which are fully and properly labeled as to the presence or potential presence of allergens.

Altitude shock

Altitude shock refers to the exposure of ice cream to altitudes substantially different, either higher or lower, from the elevation at which it was produced. This affects ice creams made at high altitude and distributed at low altitudes as well as ice creams made at low altitudes and distributed at high altitudes. The air pressure inside the air bubble is that of the location at which the ice cream is made. This pressure then gets "locked in" after hardening. If the ice cream remains at classical storage temperatures, i.e. ~ –20°F, (~ –29°C) without change, no effects are noted. However, if the ice cream undergoes HEAT SHOCK and warms even slightly, the air bubble will expand or contract depending on the direction of the pressure differential under which that heat shock occurs. Thus, effects can include EXPANSION, SHRINKAGE or both depending on the influences of the environment during distribution. Ultimately, the tolerance of the air bubble to such changes needs to be managed. No one solution may work in all cases. In general, other approaches, such as making and selling ice cream only within the atmospheric pressure conditions under which it was made, managing distribution supply lines to minimize effects, managing packaging fill (i.e., underfill to compensate for expansion), or similar steps may be necessary.

Amino acid

An amino acid is an ORGANIC ACID in which a nitrogen-containing group called an "amine" is present in the structure. About twenty amino acids are known. They are the basic structural elements of PEPTIDES and PROTEINS, which are made up of long chains of amino acids linked to each other in complicated ways. The complexities of protein structure in terms of composition, how molecules react to them, and how individual proteins interact with each other are the reasons for the range of functionality of proteins in ice cream.

Ammonia

Ammonia is a REFRIGERANT GAS with a characteristic pungent odor. Its chemical formula is NH_3. Ammonia is commonly used for cooling and freezing in operations where the economies of scale support the operation of a centralized refrigeration system. Care is necessary when using ammonia as it is soluble in water even under the lowest of temperatures and is toxic. If an ammonia leak occurs in a refrigeration system, contamination of ice cream can occur, rendering the ice cream unsafe to eat.

Amphiphilic

Amphiphilic (literally, "loving both") describes a compound with components that differ in their attraction to water and fat. In such compounds, one part is an entity attracted to water (i.e. hydrophilic, or water-loving), and another part is repelled by water, i.e., hydrophobic, or water-hating. In some applications amphiphilic groups are referred to as lipophobic (fat-hating) and lipophilic (fat-loving), respectively. In the ice cream context, being an amphiphile allows such compounds to function as EMULSIFIERS and WHIPPING AGENTS. This functionality is related to their ability to align themselves at the interface of fat or air with water, in which the hydrophobic portion is attracted to the fat or air and the hydrophilic portion remains attracted to the water phase. By so doing they form a protective film that reduces the tendency for COALESCENCE. See emulsifier.

Anhydrous milk fat

Anhydrous milk fat is pure milk fat derived by its separation from the water and MILK SOLIDS NOT FAT portion of milk. It is also referred to as butter oil. See dairy ingredients.

Anti-foam agents

Antifoam agents are SURFACTANTS that weaken the lamellae of air bubbles and cause them to collapse. Their application in ice cream involves their use in controlling foam in the assembly of mix ingredients or in treating rework to facilitate re-processing by removing air incorporated as overrun. However, if use rates are not limited and monitored, off-flavors and/or inability to incorporate air may occur in the final ice cream. The most commonly used anti-foam agents are based on vegetable oil, mineral oil, or silicone. Anti-foam agents differ from FOAM DEPRESSANTS in that the former are used purposely to reduce undesirable foam, while foam depressants yield undesirable loss of ability to incorporate and hold air during whipping and freezing.

Anti-freeze proteins

See ice-structuring protein.

Apparent acidity

Apparent acidity is the TITRATABLE ACIDITY (reported as percent lactic acid) naturally found (without fermentation or addition of acidulants) in milk, milk ingredients and ice cream mix. It is produced by the buffering capacity of the MILK SALTS system.

Arabic gum

See acacia gum, stabilizers.

Arabinogalactan

See acacia gum.

Aroma

Aroma is the volatile component of flavor that is perceived by olfactory structures located in the nasal passage.

Aseptic packaging

Aseptic packaging refers to packaging under sterile conditions of ice cream mix sterilized by ultra-high temperature pasteurization, which prevents microbiological contamination of the sterile product. Sterile, aseptically packaged RESALE MIX can be stored and distributed at room temperature. As desirable as storage and distribution at room temperature may be, this does not give ice cream mix indefinite shelf-life, because other factors, such as flavor and protein stability, may deteriorate, even in the absence of microbiological growth.

B

Bakery/pastry particulates

See particulates.

Batch freezer

A batch freezer is a device that freezes and whips ice cream mix in individual volumes or "batches." See freezing: hard ice cream products.

Batch pasteurization

Batch pasteurization is the process by which a given amount, or "batch," of ice cream mix is exposed to pasteurization conditions to render the mix microbiologically safe for human consumption. See mix processing.

Beater

Beater is the name given to the mechanical part of the DASHER in an ice cream PROCESS FREEZER that accomplishes the whipping of air into the mix. A beater is sometimes referred to as a "whipper." See freezing.

Bitter flavor

Bitter flavor is one of the five basic taste sensations perceived in the mouth. It is characterized by an acrid, slightly astringent nature. Certain ice cream flavorings, notably chocolate, include a slightly bitter character in their flavor profile. Otherwise, bitter flavor is undesirable. The primary non-flavoring source of bitterness is the growth of PSYCHROTROPHIC microorganisms, which break down protein as part of their metabolism.

Blast freezer

A blast freezer is a space in which packaged ice cream is HARDENED for storage. Maximum cooling is achieved by circulating very cold air under high velocity and by allowing space between individual packages or groups of packages. In specific circumstances, specialized packages may be employed to increase the heat transfer and accelerate hardening.

Bloom

Bloom is an index of the gel strength of GELATIN expressed as the force in grams required to break a gel developed under standardized conditions at a standard gelatin level. The results are expressed as numbers referred to as the "Bloom" of gelatin. The higher the Bloom, the stronger the gel. The gel strength of gelatin ranges from virtually none to ~450g. The usage level of gelatin in ice cream is determined by its Bloom strength. See stabilizers.

Blurred definition

Blurred definition is a condition in ice cream also referred to as "LACKS DIFFERENTIATION." It refers to an appearance defect in ice cream in which the boundary between different components, such as ice creams of different colors or between ice cream and inclusions, particularly syrups, does not show a clear demarcation.

Body

Body is a term that refers to the structural properties of ice cream. It is directly related to its cohesiveness as the product is being dispensed and to the perception of its structure as it is being consumed. Ice cream body is determined by many factors, including: complex interactions between individual and agglomerated elements of the fat and CASEIN MICELLE systems; the state of multiple proteins besides casein; the amount and size of ice crystals present; the level of total solids, and the RHEOLOGY of the unfrozen portion as it is affected by the control of water mobility by sweeteners, proteins, bulking agents, and stabilizers. A broad range of processing and composition variables affects the nature of the interaction of all those factors.

Boiling point elevation

Boiling point elevation is a COLLIGATIVE PROPERTY that refers to the increase in the a given control; however, it will not provide information about the specific shelf life of a specific product, given the uncertain nature of the conditions to which it will be exposed. A more practical approach can be based on the profile of consumer or customer complaints received, combined with the evaluation of products purchased at or near the sell-by date. A low level of complaints involving body/texture deterioration, or other quality attributes in most aged products would support a decision to extend the sell-by date. Ongoing monitoring to evaluate the effect of that extension is necessary.

Sherbet, water ices, sorbets: different, but not forgotten

Sherbet, water ices, and sorbets can very well be forgotten or misunderstood, being in the shadow of classical standardized ice creams or even non-standard frozen desserts (e.g., frozen yogurt, non-dairy types, generic frozen dairy desserts, etc.). However, demands on new product development, new flavors, innovative applications and approaches, cost reduction/avoidance, etc., make these frozen dessert workhorses more able to meet consumer needs/preferences and other voids that ice creams and other products simply may not be able to fill. Given this, the value of sherbets, water ices, and sorbets to any given product line cannot be understated.

Sherbet

Sherbet is a frozen dessert that, in comparison to ice cream, has much lower levels of fat (1–2%), milk solids not fat (2–4%, all of which can be whey solids), lower overrun (minimum weight 6 pounds per gallon), and higher levels of sweetener (typically 28–32%). Sherbet can be produced in any flavor; however, fruit flavors predominate. In fruit flavors organic acids are added to enhance flavor—a level of acidity of at least 0.35% (calculated as lactic acid) is required by the FDA Standard of Identity. The Standard also includes minimum requirements for the quantity of fruit: citrus—2%; berries—6%; and other fruits—10%.

The body and texture properties of sherbets range from the traditional icy, cold style to a smooth, creamy product with a mouth feel close to that of ice cream. Initially, sherbet was considered to be a refreshing frozen dessert particularly appropriate for consumption during warm seasons. Its refreshing qualities were provided by a dense, low-overrun structure that provided more mass per spoonful than ice cream and, therefore, more cooling effect. The cold mouth feel was enhanced by relatively large ice crystals that provided an icy texture. Later, the industry became aware that the inclusion of typical ice cream emulsifier systems and advanced stabilizers makes it possible to produce a sherbet with eating properties more like those of ice cream. Emulsifiers produce stronger, more stable and smaller air bubbles that add to creaminess, while alternative stabilizer systems provide enhanced control over ice crystal growth. Those factors also provide properties at the freezer suitable for the production of extruded products. It is now possible to produce sherbet products over a broad range of properties, including the achievement of overrun in the normal ice cream range. Such products would fall below the weight limitations of the Standard of Identity; however, they would have legal acceptance if identified by a fanciful name other than "sherbet." If properly formulated, more mainstream flavors such as vanilla, chocolate or variants of vanilla and chocolate may be possible, thus, compounding the subtle differences between "sherbet" and ice cream.

Water ice

Water ices are frozen desserts that consist of mainly water, sweetener, acidulant, flavor, color, and stabilizer. They can be considered as sherbets in which no dairy ingredients are present. They are sometimes produced as quiescently frozen novelties. They may or may not have added air whipped into them and may or may not have added emulsifiers as well. If air is whipped into the mix, special formulation considerations are necessary. The development of water ices has followed a path similar to that of sherbet, in that they have evolved from a cold, icy product to include products with a creaminess and smoothness similar to ice cream. Such upscale water ices are usually marketed as "sorbet."

Sorbet

No regulatory definition for "sorbet" exists. Thus, it is conventional wisdom that defines it as an upscale water ice. The basis for the "upscale" characterization is added quality that comes from the fact that products identified as sorbet usually derive at least part of their sweetening from bland fruit juice concentrates (often apple or pear), fruit juice concentrates of the select characterizing flavor (e.g., strawberry) and often contain discrete fruit pieces. As a result, sorbet contains more fruit solids than water ice (which usually has none). The overrun level in sorbet is generally ~15–25%; water ices may have no added air when frozen, particularly those that are quiescently frozen.

Sweetener costs I

Sweeteners in conventional ice cream compositions include carbohydrates such as sucrose, corn syrup, high fructose corn sweeteners (HFCS) and, to a lesser degree, maltodextrins. Sweetener functionality includes providing sweetness, low-cost solids, water immobilization, freezing point management, positive eating characteristics, and enhanced heat-shock resistance.

The U.S. Code of Federal Regulations allows the use of all safe and suitable sweeteners in ice cream and other frozen desserts. That makes possible the achievement of cost reduction through the use of non-traditional sweetening systems.

Historically, sweetener-related cost reduction became possible with the development of alternative, lower-cost carbohydrates such as corn syrup, high-fructose corn syrup (HFCS) and maltodextrins. Considerations involved in the use of such ingredients included the need to maintain key product properties, such as sweetness, other flavor elements, body and texture.

Recently, variations in sweetener pricing have occurred. Thus, the rules of engagement relative to achieving cost reduction by managing sweetener usage have changed as well. At the same time, the industry is giving more consideration to the use of non-traditional ingredients. As a result, novel approaches to sweetener use and functionality are now possible. Although the classical formulation rules of thumb still apply, these new approaches can provide even greater opportunities for cost reduction and product improvement.

Identifying novel and significant cost savings opportunities involves consideration of the concept of "cost per unit sweetness" (CUS). Every sweetener, whether conventional or high intensity, has a sweetness equivalence. That is a value that represents the contribution of a given ingredient to perceived sweetness compared to that of sucrose, which is arbitrarily given a sweetness of 1.0. In addition, sweeteners have a variable cost per pound. From sweetness equivalence and cost per dry pound, the CUS of any given sweetener can be calculated by dividing the cost per pound by the sweetness equivalence value. For example, a high-intensity sweetener with a sweetness equivalence value of 200 (i.e., 200 times the sweetness of sucrose) and a cost of \$15 per pound would have a CUS of \$15 ÷ 200 = \$0.075.

The cost per unit sweetness (CUS) for some high-intensity sweeteners is now less than that for sucrose and other alternative sweeteners. That makes them highly attractive as economical sources of sweetness. It is therefore appropriate to consider extending the application of these materials from their traditional use in sugar-modified products (e.g., no-sugar-added or sugar-free) to being used in combination with classical carbohydrate sweeteners in conventional ice creams.

A key element of that concept involves the need to replace the bulking effect that is lost when the level of conventional sweeteners is reduced. That brings into play the use of bulking agents, such as maltodextrins, which provide little sweetness.

A significant impact of the partial replacement of conventional systems with high-intensity sweeteners is to increase freezing point. If managed properly, this can have a desirable effect on texture stability by reducing the average initial size of ice crystals through increasing the amount of water frozen in the freezer, where conditions are most favorable to the formation of small ice crystals. Increasing freezing point also reduces the amount of water involved in melting and freezing during any given episode of heat shock, which reduces the rate of growth of ice crystals during distribution and storage.

For example, in a typical 10% fat ice cream composition, reducing sucrose by 25%, replacing the sweetness lost with a high-intensity sweetener and using maltodextrin to maintain total solids would increase the freezing point by about 0.5 degrees F. That would increase the amount of water frozen at a typical exit temperature by about 10% and reduce the amount of water involved in any given heat shock episode by the same degree. Both those effects represent a positive influence on the texture quality of the product when it reaches the consumer. In addition, the managed use of maltodextrin for bulking could have an additional positive effect on reducing ice crystal growth and adding to mouth feel via a contribution to water immobilization.

In sum, the use of blends of high-intensity sweeteners with conventional sweetener systems can produce significant cost savings and at the same time provide improved product properties.

Sweetener costs II

Modification to any sweetener system involves understanding four key functional elements: flavor (sweetness and other influences); freezing point depression (influence on the dynamics of frozen water); bulking (contribution to total solids); and control of water mobility. Achieving desirable objectives (cost reduction, heat shock stability, etc.) with minimal effects on eating characteristics and consumer appeal is complicated, as sweeteners vary substantially with regard to all these elements. Also, the cost per unit sweetness needs to be considered. It is best to quantify these elements for each alternative sweetener system being considered.

Quantifying sweetness is relatively easy. This involves the concept of sweetness equivalence (SE) in which sweeteners are assigned sweetness values relative to sucrose. If sucrose is arbitrarily given an SE value of 1.0, 36 DE corn syrup solids, considered to be 45% as sweet as sucrose, has an SE of 0.45. Each individual sweetener should be assigned an SE number. The total sweetness of a mix is the sum of the sweetness contributions of individual sweeteners, each of which is calculated by multiplying SE by use rate. The relatively low SE of lactose makes the matter of whether to include it in sweetness calculations optional. When the calculated sweetness falls within ± 0.5% of a target (15% is a classical target for ice cream), the difference will not likely be noticed. Outside this range, it is wise to re-evaluate the effect of the change.

Assessment of non-sweetness flavor factors cannot be done quantitatively, but must be based on the effect of any individual sweetener on flavor profile (e.g., aftertaste, compatibility with added flavors, etc.), and, ultimately, by means of product sensory evaluation.

Albeit a complex calculation, freezing point depression and its effect on freezing profile can be calculated with precision. The importance of freezing profiling cannot be understated. Freezing profiling helps understand the dynamics between ice and water at any given temperature. Comparing mixes and water behavior throughout the freezing process is useful in understanding freezing functionality, sensory appeal and distribution tolerance.

The bulking effect of sweeteners is simple to evaluate by comparing total solids levels of the current composition and alternatives. If the difference in total solids between two mixes is within ± 0.5% of each other (all other elements being equal), it is unlikely any sensory property will be negatively influenced. However, too high or too low solids levels can result in sticky/gummy or coarse/icy ice cream, respectively.

It is also important to consider changes to non-sweetener components that may be helpful. If equivalency of freezing point depression involves slightly lower total solids, parity can be restored by increasing milk solids not fat. Similarly, compensation for reduced WCI can be made by adjusting the stabilizer level.

Whey replacement of skim milk solids

Sweet whey has been an effective and economical partial replacement for milk solids not fat (MSNF) for years. Although considered an economic commodity, whey should be used and managed like any other "high tech" ingredient. Sweet whey contains lactose and soluble minerals in concentrations much greater than in skim milk solids and, thus, has a greater effect on freezing point depression. Normally, use of sweet whey at the allowed 25% replacement of MSNF (USA) can be done without much difficulty. However, when aggressive mix ingredient cost reductions are considered using whey and other ingredients, the compounded effects of all ingredients can adversely influence freezing, filling performance, hardening, flavor, body/texture, and freeze/thaw stability. At no time is it recommended to have more than 50% of total protein as whey protein. Off-flavors from oxidized residual fat and use of bleaching aids to whiten sweet whey can impact both the color and flavor of finished frozen desserts. Proper selection and management of the specific sweet whey ingredient are critical. A good rule is to select sweet whey from processes that produce cheeses with the lightest color and lowest flavor profiles. Additionally, sweet whey that you might receive may come from different cheese processes and different plants blended to allow for more efficient whey processing. Consult your supplier to fully understand the impact of their whey processing on your frozen dessert quality.

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Dr. Tharp holds B.S., M.S. and Ph.D. degrees in Dairy Science from The Pennsylvania State University. University Park, Pennsylvania. He has been closely involved with the dairy and ice cream industry for his entire career, beginning with activity in his family's business, Tharp's Ice Cream, in Shamokin, Pennsylvania. Dr. Tharp is the inaugural recipient of the International Ice Cream Association Lifetime Achievement Award (March, 2006). After academic service on the faculties of the University of Wyoming and The Ohio State University, Dr. Tharp managed the technical affairs of two major suppliers of high-tech dairy product ingredients, including service as International Technical Director for Germantown International Limited. His professional activities have included a major focus on ice cream on six continents. He has achieved international recognition for his scientific and technical expertise and commercial insights, including participation as an enthusiastic and authoritative lecturer at short courses, seminars, workshops and technical conferences around the world. That has included service as a principal lecturer at the annual Penn State Ice Cream Short Course for over 35 years. He is currently Adjunct Professor of Food Science at Penn State and served as chief ice cream judge at the Intercollegiate Dairy Products Evaluation Contest for over 30 years. Since 1996, he has been co-developer and presenter of "Tharp & Young On Ice Cream Technical Short Course, Workshops and Clinics." Starting in 1999, he has co-authored quarterly columns for Dairy Foods magazine covering a wide range of ice cream science and technology topics. He is an active consultant to the ice cream industry worldwide.

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Dr. Young lives with wife, Lynn, and children, Benjamin and Lillian, in Houston, Texas, and follows with great interest each of their hobbies and activities, including the love of musical theater and sports. He is a former ice hockey player, collegiate referee, and youth hockey coach.