H. Douglas Goff
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Seventh Edition

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Preface

We are pleased to present the seventh edition of the long-standing title, *Ice Cream*. The first edition was written by Prof. Wendell S. Arbuckle of the University of Maryland and published in 1966. Prof. Arbuckle had joined Prof. J. H. Frandsen in coauthoring *Ice Cream and Related Products* in 1961. Frandsen was the senior author of two other ice cream books in 1915 and 1950. So, the lineage of this book can be traced back to the infancy of the industrial ice cream industry. Prof. Arbuckle published subsequent editions in 1972 (second), 1977 (third), and 1986 (fourth), before his death in 1987. In 1996, Prof. Robert T. Marshall of the University of Missouri completely revised the Arbuckle manuscript and published the fifth edition under the names of Marshall and Arbuckle. We (H. D. Goff and R. W. Hartel) joined Prof. Marshall to prepare the sixth edition, published in 2003, under the names of Marshall, Goff, and Hartel. Prof. Marshall has since retired, leaving us to prepare the seventh edition.

We have completely revamped this edition. Every chapter has been rewritten, updating with state-of-the-art knowledge and new references as appropriate. Material has been realigned to make what we feel is a more coherent presentation. New chapters on ice cream structure (Chap. 11) and ice cream shelf life (Chap. 12) have been added. We have made the book suitable for an international audience by converting completely to SI units, although we indicate the equivalent US unit as appropriate, and we have incorporated international production and consumption data, legislation information, and global industry practices.

Both of us have been involved in ice cream research for 25 years. Prof. Goff has also been teaching ice cream courses at the University of Guelph and in various places around the world for 25 years. This book reflects our combined knowledge. We have maintained the focus on science and technology of ice cream. We do not present any information about marketing, retailing or restaurant operations. The book is intended for people with a science and technology background, or at least those who want to learn more of the technical aspects of ice cream production. It is intended for anyone involved in the industry, from Research and Development, Quality Control, or Manufacturing in large-scale operations right through to small-scale entrepreneurs who want to understand the principles behind the product they

are making. Suppliers to the industry should gain a tremendous insight into the complexities of the product, the functional roles of the ingredients, and the manufacturing and cleaning processes employed by the industry. And, of course, it is for students, both Undergraduate students who are learning about ice cream, perhaps with the intention of entering the industry some day, and Graduate students who are furthering our knowledge with their research. The students of today are the industry leaders of tomorrow.

We dedicate this edition to our own students who have contributed thousands of hours to ice cream science. This edition has been a year in the making and much family time has been consumed, so sincere appreciation is extended to our families without whose support and encouragement we would not have accomplished our goals. We also gratefully acknowledge all of the contributors to various chapters.

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Introduction

Frozen dairy desserts are characterized by containing milk solids (which may or may not include milk fat) and being consumed in the frozen state, and they are frequently also aerated. Within the frozen dairy desserts category, ice cream is the most widely consumed product. Our meaning of ice cream varies globally, due to differing regulations and traditions of composition, and hence can be found with many formulation variations:

- Regular ice cream (usually defined by minimum levels of fat, which may be dairy or nondairy, and also minimum levels of either food solids or milk protein or milk solids, alone or in combination).
- Higher-fat premium-type products, although these usually also meet the normal definitions of ice cream.
- Low-fat or nonfat versions or no-sugar-added or sugar-free versions, which may or may not meet the usual definitions of ice cream.

All of these categories are available in multiple flavors and shapes (including handheld or impulse products). The category can be further divided according to hard-frozen products, those that contain a second freezing step after the dynamic freezing step, and soft-frozen products, those that are consumed directly and immediately after dynamic freezing with no hardening step. Also, frozen dairy desserts include frozen custard, frozen yogurt and sherbet, all of which could be hard or soft frozen, and frozen milkshakes and smoothies. Frozen desserts in general (again, characterized by being consumed in the frozen state and may also be aerated) would also include products that contain no milk-derived ingredients, for example, sorbets, water ices, or plant-protein-based products such as soy/tofu frozen desserts.

Ice cream, and most all of the other frozen desserts described above, generally contain seven categories of ingredients: fat, milk solids-not-fat (the principal source of protein), sweeteners, stabilizers, emulsifiers, water, and flavors. For the wide range of frozen desserts, production is similar. Mix, the unfrozen blend of ingredients,

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is manufactured by blending, pasteurizing, homogenizing, cooling, and aging at 4 °C. Subsequently the mix is frozen to approximately −5 °C through a scraped-surface freezer while under shear ("dynamic" freezing, which incorporates air and produces small, discrete air bubbles and ice crystals). Flavoring materials that will remain discrete in the product (fruits, nuts, candy, or bakery pieces) can be added after dynamic freezing, followed by packaging or shaping (as in the case of "novelty" or "impulse" products). Finally these products are blast frozen to a temperature of −25 to −30 °C. Although our book is entitled "Ice Cream," and has been since its inception more than 50 years ago, it should be recognized that our content coverage is sufficiently broad to encompass all frozen dairy desserts, indeed all "ice cream-like" frozen desserts, due to similarities in both composition and manufacturing.

The Changing Characteristics of the Industry

The ice cream industry globally consists of a few multinational (e.g., Unilever, Nestle, Häagen-Dazs, Baskin-Robbins) and national firms that supply products sold either through food or mass merchandising stores or retail/food service, and a very large number of small-medium local or regional firms that supply products sold through local retailers or scooping shops. Globally, these artisanal ice cream manufacturers make up about 10% of production volume but as much as 20% of the value of the industry, although precise numbers are difficult to determine. The ice cream industry is estimated to be valued at US$ 73.8 billion in sales worldwide (data from Euromonitor International, 2011), growing at >5% per year (2006–2010) with the biggest growth in Latin America, Eastern Europe, Africa, and the Middle East (all growing at >10% per year, 2006–2010), although Western Europe and North America, the two largest markets, show much lower growth. Western Europe represents the largest market, with sales of US$ 24.1 billion in 2010, followed by North America at US$ 17.1 billion, Asia Pacific at US$ 15.9 billion, Latin America at US$ 6.5 billion, and Eastern Europe at US$ 4.9 billion. By country, the US market was the largest, at US$15.6 billion, followed by Italy at US$ 6.8 billion, China at US$ 4.4 billion, and Australia, Brazil, Russia, and the United Kingdom, all at US$ 2.2–2.4 billion.

Ice cream is considered by most people to be a dairy product, and if manufactured with fresh cream and fresh milk as ingredients, more than 80% of its content is dairy-derived. However, if manufactured with a nondairy fat and reconstituted milk powder, in many cases less than 10% of its content is dairy-derived, and thus it can just as easily be considered a food product with a dairy ingredient. Hence, some manufacturers, particularly in the United States, are multiproduct dairy companies while globally, ice cream is also manufactured by several multinational food companies, including Nestle, Unilever, and General Mills, who do not necessarily produce other dairy products.

In North America, the organization that represents most of the large firms of the industry is the International Dairy Foods Association (IDFA), headquartered in Washington, DC. Many of the small firms belong to the National Ice Cream Retailers

Association (NICRA), headquartered in Columbus, OH. Across the world, there are many other ice cream-specific trade associations, such as the Ice Cream Alliance in the UK, or national dairy trade associations that also represent ice cream interests. In Europe, ice cream associations of the various EU member countries are represented by Euroglaces, the European Ice Cream Association, with headquarters in Brussels. Globally, the International Ice Cream Consortium is an association of noncompeting ice cream companies that cooperate on technical and business matters. The International Dairy Federation, headquartered in Brussels, also has an interest in the ice cream sector, having sponsored at least three major international conferences on the subject in the last 15 years.

The history of frozen desserts shows that great efforts have been made to produce and consume these highly enjoyable foods. Those who first consumed them were the elite of society. Today's offerings cater not only to more wealthy consumers but also to the masses, with prices of products in the market varying by as much as a factor of 10 for equivalent volumes. It is estimated that 90% of Americans eat ice cream. The average retail price of supermarket ice cream is about $2.00–3.00 per liter, about eight servings, making the cost of a serving average less than $0.25–0.40, a remarkable buy for the nutrition and appetite satiation that it brings.

Production and Consumption Trends

Global production of ice cream was 16.3 billion liters in 2010, up from 15.3 billion liters in 2006 (Table 1.1). Of the global production in 2010, 31% was in Asia Pacific, 29% in North America, 20% in Western Europe, 7% in Eastern Europe, and 6% in Latin America. By country, US was the largest producer at 4.4 billion liters, followed by China at 2.9 billion liters, Japan at 0.9 billion liters, Germany at 0.65 billion liters, and Italy at 0.6 billion liters (Table 1.1). Global per capita consumption of ice cream and related products (it is difficult to know exactly what is included in these data from different countries, due to differing regulations on the definition of "ice cream") is presented in Table 1.2. In 2010, Australia ranks first at 17.9 L, followed by New Zealand at 15.8 L, the United States at 14.2 L, Finland at 12.5 L, Canada at 10.5 L, and Italy at 10.0 L. Many Western European countries fall into the range of 7–10 L per capita. Even though China and Japan are world leaders in production, their per capita consumption is much lower than North America and Western Europe, with Japan at 6.9 L and China at 2.1 L, below the world figure at 2.4 L (Euromonitor data 2011). It is also interesting to compare the US$ annual expenditure on ice cream per capita by country, which provides not only a measure of the size of the market but also an indication of the sophistication of products in that market, although average cost of living in these countries also needs to be taken into account. By this measure, in 2010 Italy is the top at US$ 113 per capita, followed by Australia at US$ 103, Finland at US$ 88, Norway at US$ 84, Sweden at US$ 71, and Denmark at US$ 65. The USA sits at US$50 per capita while China is at US$ 3 per capita on ice cream expenditures.

Table 1.1 Global ice cream production by year, region, and country, '000 kL (data from Euromonitor International, 2011)

	2006	2007	2008	2009	2010
World	15,370.0	15,678.8	15,742.7	16,001.1	16,347.5
Asia Pacific	4,317.9	4,536.9	4,724.5	4,722.5	4,901.1
North America	4,898.2	4,793.8	4,592.7	4,726.9	4,742.9
USA	4,531.0	4,430.1	4,230.5	4,367.4	4,386.4
Western Europe	3,226.2	3,284.5	3,300.4	3,384.1	3,436.7
China	2,484.7	2,639.0	2,776.1	2,740.2	2,868.6
Eastern Europe	1,131.1	1,158.0	1,147.6	1,111.8	1,128.9
Latin America	874.7	949.9	991.5	1,031.7	1,075.3
Japan	873.9	880.9	887.5	886.1	884.0
Germany	674.3	677.1	659.9	656.1	651.7
Italy	546.1	572.6	561.8	594.2	607.0
Middle East and Africa	491.5	517.7	542.5	570.1	597.6
United Kingdom	495.4	488.1	496.2	515.1	531.7
Russia	555.4	540.8	517.7	505.6	499.1
Australasia	430.4	438.0	443.4	454.0	464.9
Australia	362.2	368.9	374.6	385.8	396.1
France	370.5	368.7	369.4	386.9	395.3
Brazil	267.3	310.2	325.4	345.3	369.2
Canada	367.2	363.6	362.2	359.5	356.5
Spain	337.7	342.8	349.3	349.8	350.9
South Korea	266.6	270.1	262.4	263.8	266.2
Turkey	125.8	156.2	179.7	190.9	203.5
India	95.1	115.3	137.6	158.7	183.3
Argentina	135.0	146.5	159.3	169.7	175.6
Ukraine	171.5	185.8	177.9	149.7	164.2
Poland	113.7	123.9	134.8	143.0	152.5
Indonesia	113.6	123.3	135.1	142.7	149.2
Chile	124.5	129.0	132.7	134.0	136.9
Iran	99.3	104.8	110.4	116.9	124.0
Mexico	111.3	115.5	112.6	112.7	113.4
Netherlands	83.3	85.3	89.3	95.4	100.2

Global and regional market shares by volume and by monetary value according to point of manufacture/consumption—take-home products, impulse products, and artisanal/parlor sales—are shown in Tables 1.3 and 1.4. The take-home category is defined as grocery store purchases and home consumption, the impulse category is categorized by handheld, single serving eat-on-the-spot products (sometimes referred to as novelty products), while the artisanal and parlor category is defined as being manufactured at the site of purchase and consumption or sold directly by the manufacturer to the consumer (e.g., ice cream parlors and street vendors). Impulse products make up the largest share by volume globally, followed closely by take-home products, although the value of take-home products is much lower than the value of impulse products. The impulse product category has been increasing in market share over the period 2006–2010, especially by monetary value. The artisanal

Table 1.2 Per capita consumption of ice cream and related products in selected countries, 2006–2010 (data from Euromonitor International, 2011)

	2006	2007	2008	2009	2010
Australia	17.5	17.5	17.5	17.7	17.9
New Zealand	16.3	16.3	16.1	15.8	15.8
USA	15.2	14.7	13.9	14.2	14.2
Finland	12.8	12.8	12.7	12.6	12.5
Canada	11.2	11.0	10.9	10.7	10.5
Italy	9.3	9.7	9.4	9.9	10.0
Norway	8.9	9.2	9.4	9.6	9.8
United Kingdom	8.2	8.0	8.1	8.4	8.6
Denmark	8.9	8.7	8.7	8.5	8.4
Chile	7.6	7.8	7.9	7.9	8.0
Germany	8.2	8.2	8.0	8.0	8.0
Sweden	8.0	7.5	7.6	7.7	7.7
Spain	7.7	7.7	7.8	7.7	7.6
Portugal	7.5	7.7	7.8	7.6	7.5
Ireland	7.9	7.6	7.3	7.3	7.2
Japan	6.8	6.9	7.0	6.9	6.9
Slovenia	5.7	6.0	6.2	6.4	6.5
Belgium	6.2	5.9	5.8	6.1	6.3
France	6.1	6.0	5.9	6.2	6.3
Netherlands	5.1	5.2	5.5	5.8	6.1
South Korea	5.5	5.6	5.4	5.4	5.4
Argentina	3.5	3.7	4.0	4.2	4.3
Ukraine	3.7	4.0	3.9	3.3	3.6
Russia	3.9	3.8	3.6	3.6	3.5
World	2.3	2.4	2.3	2.4	2.4
China	1.9	2.0	2.1	2.1	2.1
Brazil	1.4	1.6	1.7	1.8	1.9
Mexico	1.1	1.1	1.1	1.0	1.0

Table 1.3 Global market share (% by category) of ice cream characterized by point of manufacture/consumption, 2006–2010 (data from Euromonitor International, 2011)

	Take-home products		Impulse products		Artisanal/parlor	
	Volume	Value	Volume	Value	Volume	Value
2006	44.0	26.5	48.3	50.8	7.7	22.7
2007	43.1	26.0	49.0	51.0	7.9	23.0
2008	42.0	25.1	50.0	51.7	8.0	23.2
2009	42.4	24.9	49.4	52.0	8.2	23.1
2010	41.9	24.6	49.8	52.6	8.3	22.8

and parlor market is small but has been increasing in volume over the period 2006–2010, but this is not reflected by similar increases in value. There are very large regional differences in market share distribution, impacted in large part by the presence of home freezers. In North America, the take-home product market is

Table 1.4 Regional market share (% by category) characterized by point of manufacture/consumption, 2010 (data from Euromonitor International, 2011)

	Take-home products		Impulse products		Artisanal/parlor	
	Volume	Value	Volume	Value	Volume	Value
North America	70.7	38.5	23.9	36.4	5.4	25.1
Latin America	44.4	24.0	41.3	57.5	14.3	18.5
Western Europe	42.6	23.1	38.4	43.6	19.0	33.3
Eastern Europe	39.4	29.6	56.3	61.6	4.3	8.8
Asia Pacific	12.3	9.4	84.9	78.6	2.8	12.0
Australasia	65.5	28.5	30.5	52.4	4.0	19.1

Table 1.5 Production statistics for frozen desserts in the United States, 1990–2010

	Year					
	1990		2000		2010	
Product	Million Gallons	% of total	Million Gallons	% of total	Million Gallons	% of total
Regular ice cream	823.6	57.7	979.6	60.9	920.2	60.5
Low- and nonfat ice cream	352.3	24.7	404.1	25.1	398.2	26.2
Frozen yogurt	117.6	8.2	94.5	5.9	74.4	4.9
Sherbet	50.3	3.5	51.9	3.2	53.1	3.5
Water ices	50.7	3.6	65.8	4.1	59.7	3.9
Others	32.4	2.3	11.6	0.7	14.7	1.0
Total	1,426.8	100.0	1,607.6	100.0	1520.3	100.0

Source: USDA, National Agricultural Statistics Service, as reported by IDFA (2010)
Note: 1 US gallon = 3.78 L

considerably larger by volume than the impulse product market, but by value they are close. This is in stark contrast to the market shares in Asia Pacific, for example, where impulse products make up a very large share of the ice cream volume and value. Western Europe tends to be more evenly split between the two categories. In Western Europe, the artisanal and parlor markets are also quite substantial, fully 1/3 of the value of the industry. In North America, this market represents 1/4 of the value of the industry.

Although not quite the largest consumer of ice cream and related products, the United States is the largest producer, at 1,520 million US gallons (5.75 billion liters) in 2010. This compares to productions of 1,427 million US gallons in 1990 and 1,607 million US gallons in 2000, indicating a slight decline in the last decade (Table 1.5). Per capita production also shows a decline from 22.76 quarts (21.5 L) in 2000 to 19.10 quarts (18.1 L) in 2010 (Table 1.6). The 20-year trend in production shows steady growth in low-fat and nonfat products and decline in frozen yogurts (Table 1.5), while from per capita data we see a decline in all categories from 2000 (Table 1.6), especially in regular ice cream which dropped from 13.88 (13.1 L) quarts to 11.99 quarts (11.3 L), down from a high of 15.55 quarts (14.7 L) in 1960. In 2010, US frozen dairy dessert production could be subdivided as follows: 60.5% regular ice cream, 26.2% low-fat and nonfat ice cream, 4.9% frozen

Table 1.6 Per capita production of frozen dairy desserts in the United States (quarts), 1920–2010

Year	Ice cream	Low-fat and nonfat	Frozen yogurt[a]	Sherbet	Water ices	Others	Total
1920	6.43						6.43
1940	9.64	0.32		0.24		0.09	10.29
1960	15.55	3.23		0.91	0.74	1.11	21.54
1970	14.95	5.63		0.96	0.73	1.15	23.42
1980	14.61	5.17		0.80	0.59	0.41	21.58
1990	13.21	5.65	1.89	0.81	0.81	0.52	22.89
2000	13.88	5.66	1.24	0.75	0.93	0.16	22.76
2010	11.99	5.19	1.16	0.70			19.10

Source: Data published by the US Department of Agriculture and reported by IDFA, 2011
Note: 1 US quart = 0.945 L
[a]Data were not collected by USDA on frozen yogurt production before 1989

yogurt, 3.9% water ice, and 3.5% sherbet (Table 1.5). 93.5% of regular ice cream was hard frozen, while 6.5% was soft frozen. Of the low-fat category, 39% was hard frozen while 61% was soft frozen and of frozen yogurts, 29% was hard frozen while 71% was soft frozen, demonstrating the dominance of lower-fat ice cream products and frozen yogurts for soft-frozen mixes.

Of the 1,520 million US gallons (5.75 billion liters) of frozen desserts produced in the United States in 2010, California leads all states in the production of frozen desserts with 169 million US gallons per year, followed by Indiana at 110 million US gallons, Texas at 72 million US gallons, and Pennsylvania at 51 million US gallons. These four states produced 25% of the US production. The number of plants producing ice cream dropped from 1,628 in 1970 to 949 in 1980 to 713 in 1990 and to about 400 in 2000, and that has remained constant through 2010. During the same time, production per plant increased dramatically. For example, the average production per plant in 2010 was nearly four million US gallons (15.1 million liters) compared with 1.1 million US gallons in 1985. In 2010, the ice cream industry employed 18,500 people with a total annual payroll of US$ 750 million. The value of shipments from production was close to US$ 8.9 billion. Supermarket sales of packaged ice cream and sherbet represented US$ 4.2 billion and frozen novelties US$ 2.6 billion.

There are many thousands of retail stores and foodservice establishments that freeze ice cream, yogurt, sherbets, sorbets, and ices. However, most of the mix frozen by these firms is made in large factories that deliver directly to the ice cream retailer's door. The amount of frozen dessert mixes produced by the industry for freezing outside the mix-producing plant exceeds 800 million gallons in the USA. Managers of most small establishments have found it to be far more economical to purchase pasteurized mix than to make it in-house. The products are personalized by the ways they are flavored, frozen, packaged, handled, marketed, and served.

Monthly production figures for the United States indicate that ice cream consumption is seasonal (Fig. 1.1); however, it is much less so than former years.

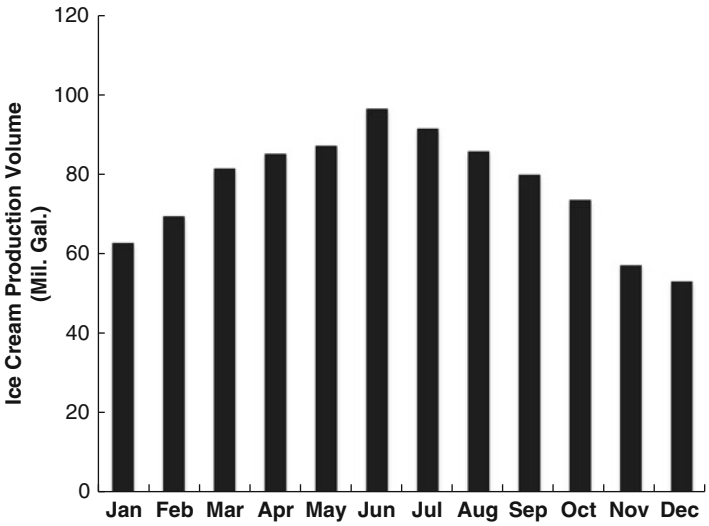

Fig. 1.1 Ice cream production volume by month in the United States in 2010. Source: Data published by the US Department of Agriculture and reported by IDFA, 2011

Whereas, in 1921 production in July was twice the monthly average for the year, this statistic dropped to 1.6 times the monthly average by 1941. Further leveling of production followed, and for the last 45 years production in July has ranged from 1.2 to 1.3 times the monthly average for the respective years. Lowest production occurs in November through January with average production at 70–80% of the monthly average for the year.

The ice cream industry is very progressive with many new product introductions annually. Some of the current formulation trends in the industry include a growing interest in "reduced" or "no" claims for fat, calories, or sugar; the use of nutritionally functional additives (e.g., vitamins or minerals) or flavors showing added nutritional functionality (e.g., high in antioxidants); a renewed focus on frozen yogurt, particularly with probiotic cultures, although this represents a very small segment of the overall total market of frozen desserts; and formulations approved as kosher or halal compliant. Products are also marketed with a growing social awareness, including fair trade to primary producers, organic products, environmental sustainability, and social responsibility by aligning products with particular social justice causes.

In Canada, total frozen dairy dessert mix production declined from 171,271 kL in 2006 to 111,938 kL in 2010, which appears to be a substantial loss of market. However, in 2006, nondairy fats became permitted in "ice cream"-like products due to a change in regulations, provided they are clearly labeled as "frozen dessert" and not "ice cream," and the production of these products is not captured in the frozen dairy dessert mix category. This probably accounts for such a dramatic decline in the production statistics, although probably not representing a decline in total

production per se. In many other countries of the world, "ice cream" can be made from nondairy fats while "dairy ice cream" must contain milk fat. This makes comparison of statistics difficult. Canadian hard ice cream production declined from 299,256 kL in 2006 to 189,310 kL in 2010, although during this same time period, low-fat/nonfat frozen dairy desserts grew from 29,168 to 40,227 kL, soft ice cream grew from 19,955 kL to 21,971 kL, and sherbets grew from 5,426 kL to 5,966 kL.

A Brief History of Ice Cream

A very thorough global history of ice cream was commissioned by Unilever and published to celebrate the millennium (Reinders 1999). Weir and Weir (2010) and Quinzio (2009) have both written recent histories of ice cream, and a history of American ice cream was written by Funderburg (1995); the reader is referred to these monographs for complete details of the evolution, sociological impact, and industrial development of ice cream.

Although the traditions of ice cream consumption, and hence manufacture, run very deep in the United States, the product was introduced to the United States from Europe, and many European countries not only have a long history with ice cream but also have a long-standing sociological love affair with the product that mirrors the American experience. Ice cream was not invented per se but rather evolved from centuries-old practices involving the cooling of foods and beverages with snow, which was described in Roman historical writings back to the first century AD. Legend has it that when the thirteenth-century Venetian merchant Marco Polo returned to Italy from his famous journey to the Orient, he brought recipes for water ices said to have been used in Asia for thousands of years. This legend, however, is unsubstantiated based on any historical writings. So, too, is the legend surrounding the Italian-born Catherine de' Medici, who is said to have brought Italian-trained chefs to the Royal Court of France after her marriage in 1533 and with them the secret of ice cream.

Probably the first major step in the evolution of modern ice cream came with the development of processes for freezing of water using salt (or saltpeter) and ice, which was described as early as 1530 in Italy but was not utilized for the freezing of sweet food mixtures until the middle of the seventeenth century. By then, water ices were beginning to be served at the banquet tables of the European royal courts and nobility. Perhaps the first published recipe for water ices came from the French *confiturier* Nicolas Audiger in 1692, in which he claimed he had been serving such desserts at the Court of Louis XIV of France since 1662. François Massialot also described the freezing of water ices in his cookery book also of 1692. In a 1712 edition, Massialot added a recipe that included milk, which he referred to as "Fromage à l'Angloise." Recipe books from the early eighteenth century suggest that the English preferred recipes based on cream and sugar while the French preferred recipes for water ices or milk and egg whites. This dairy-based "warm-eating" ice cream evolution was perhaps more associated with colder climates, compared to the "cold-eating" sorbets and water

ices of the Mediterranean, warm-climate, countries. The first English recipe for dairy-based ice cream appeared from Mary Eales, confectioner to Queen Anne, in 1733 and was repeated again by Hannah Glasse in her cookery book of 1742. Three cookery books devoted entirely to ice cream appeared in the middle of the eighteenth century from France, the first in 1750 by Menon, the second in 1751 by Joseph Gilliers, and the third in 1768 by M. Emy, a 240-page treatise, *L'Art de Bien Faire les Glaces d'Office*. It gave formulas for "food fit for the gods" and offered, besides the scientific and practical, theological and philosophical explanations for phenomena such as the freezing of water. Very elaborate porcelain serving pails and dishes for ice cream and water ices that consisted of inner and outer bowls for maintaining the dessert in an ice/salt slurry, to keep it cold, also began to appear in the eighteenth century (e.g., Sèvres from France, which was founded in 1738).

In 1686, the Cafe Le Procope was founded in Paris by an Italian named Francesco Procopio Dei Coltelli, and water ices were manufactured and sold. This restaurant is still operating today. Coltelli perhaps began the migration of Italian-trained artisanal ice cream makers to other European countries, notably England, where they carried on their trade. If the Italians didn't invent ice cream, they certainly contributed to bring it to the people on the street. The Italian "Hokey Pokey" man, a corruption of their cries in Italian *O, c'è un poco* ("try a little"), became well established as the street vendor of ice cream, not only in England but throughout continental Europe.

Honey was probably the first major sweetener used for frozen desserts, although the manufacture of sugar preceded the development of the ice cream industry. Sugarcane was grown in India where a process for making sugar from it was known as early as the first century. However, the use of bone in the refining process was frowned upon. The first authentic evidence of crystalline sugar dates from Persia in AD 627. By the eighth century, a process of refining was used in Egypt, Mesopotamia, and Spain. The sugar industry was established in Europe during the reign of Napoleon in the early 1800s. Growth of sugarcane in tropical regions of the Americas began in the sixteenth century. In the mid-eighteenth century, white cane sugar in loaf form costs as much as $2.75 per pound. The development of beet sugar in the early nineteenth century caused prices to drop so that the masses could afford the sweetener.

Ice cream probably came to the United States with the early English colonists. The first written evidence of ice cream in America was in a letter of May 17, 1744 by a guest of proprietary Governor William Bladen of Maryland. The letter stated that "a dessert no less curious, among the rarities of which it was composed, was some fine ice cream which with the strawberries and milk, eat most deliciously." Thomas Jefferson gets credit for introducing vanilla to America following his tour as Minister to France in 1784–1789. He requested vanilla pods from Paris in 1791 when he could not purchase them in Philadelphia. The New York Gazette dated May 19, 1777 contained an advertisement that read in part "May be had almost every day—ice cream." George Washington spent about $200 for ice cream in New York during the summer of 1790. But the masses had to wait for developments of ice harvesting, insulated ice houses, and the hand-cranked ice cream freezer

invented by Nancy Johnson (patent number 3254, Sep. 9, 1843). W. G. Young patented the "Johnson Ice Cream Freezer" in 1848, and 99 others were patented during the next 25 years. The first wholesale ice cream industry in the United States was established in 1851 in Baltimore, Maryland by Jacob Fussell. Plants were established soon thereafter in Boston, St. Louis, New York, Washington, Chicago, and Cincinnati. Two of the most important contributions to the development of the industry were the perfection of mechanical refrigeration (1878) and the invention of the direct expansion ice cream freezer (1913). Ice had been scarce in summer months when people had the greatest desire to eat a cooling food. Collection of ice during winter and storing in ice houses were both labor intensive and expensive.

The development of condensed and dry milk, the introduction of the pasteurizer, homogenizer (the latter by August Gaulin of Paris, France, in 1899), separator, and improved freezers, and other processing equipment accompanied a slow growth in the industry until after 1900. The ice cream soda was introduced in 1879. Italo Marchiony, an Italian emigrant, began making edible ice cream containers for his own business circa 1896 in New York City. He was granted a patent for his special mold in 1903; however, the drawing for the patent "shows a mold for shaping cups with tiny handles—not a cone" (Funderberg 1995). A Syrian waffle concessionaire, E. A. Hamwi, started rolling waffles into the shape of a cone, and an ice cream vendor in the adjoining booth used them as ice cream containers at the 1904 St. Louis World's Fair. Several other claims for invention of the ice cream cone are provided by Funderburg (1995).

Annual production of ice cream in the United States in 1905 was only four million gallons. At that time there was no national trade organization, and only one college, the Pennsylvania State College of Agriculture, offered instruction in ice cream manufacture, the first short course having been in 1892. Most products were being made without much guidance in quality or content. In 1905, Thomas D. Cutler founded The Ice Cream Trade Journal, the predecessor to Ice Cream Field and that to Dairy Field.

In the 1900–1919 era, the United States experienced rapid industrialization and urbanization. Ice cream standards were adopted by some states, and many dairy organizations were formed. New York City was the first municipality to inspect dairy farms for sanitary milk production practices, and the first dairy show was held in Chicago in 1906. Chicago led the way toward safe ice cream and dairy foods by adopting the first compulsory pasteurization regulation in 1909; however, it left the loophole that the requirement applied to milk from herds that had not been tested for tuberculosis. In 1917, the newly organized Association of Ice Cream Supply Men, the forerunner of today's International Association of Food Industry Suppliers (IAFIS), held its first trade exposition in Boston.

In 1905, Emery Thompson, manager of the ice cream and soda fountain in a New York City department store, developed the gravity-fed batch ice cream freezer. The invention enabled nearly continuous production. The company remains under family ownership and continues to supply freezers to industry. The first ice cream filling and packaging machines were introduced by Mojonnier Brothers and Sealright firms around 1920, and in 1923 the Nizer Cabinet Company introduced

the first automatic electric freezer. The first commercially adopted continuous ice cream freezer was perfected by Clarence Vogt of Lexington, KY around 1926. The Eskimo Pie, Good Humor ice cream bar, and Popsicle were all invented around 1920. Christen Nelson invented the I-Scream bar in 1919. After Nelson took Russell Stover as his partner, Stover named the bar the Eskimo Pie. The Popsicle was first called the Epsicle in honor of its inventor, Epperson, a concessionaire of an amusement park. The idea came to him, legend has it, when he left a glass of lemonade containing a spoon in an open window on a cold night. By morning the lemonade was frozen. He immersed the glass in water and removed the frozen mass. He patented the invention in 1924. The ingenuity of Harry Burt and the prompting by his daughter led to the Good Humor Ice Cream Sucker, a chocolate-coated ice cream bar on a stick.

William Breyer opened his first ice cream store in Philadelphia in 1882. Five more stores were opened soon thereafter. By 1896, demand for ice cream caused Breyer's sons, Fred and Henry, to open their first ice cream plant and to adopt for their label the briar leaf that is still the logo of Breyer's ice cream. A second plant was added in 1904. In 1905, the Breyers Ice Cream Company became the first firm to use brine-cooled freezers. By 1914, the firm's sales of ice cream surpassed one million gallons. In 1925 and 1927, new plants opened in Long Island City, NY, and Newark, NJ, respectively, and the firm became a division of National Dairy Products Corporation. Sales were expanded to the Northeast and Mid-Atlantic states. In 1969, the firm became part of Kraftco Corporation (later Kraft, Inc.), and distribution was extended to the Southeastern United States. Sales began west of the Mississippi River in 1984. Unilever, an Anglo-Dutch company, purchased the Breyers ice cream business in 1993, combining it with the Gold Bond-Good Humor Ice Cream Company and changing the name to Good Humor-Breyers Ice Cream Company. Good Humor had been acquired by Thomas J. Lipton Ltd., a subsidiary of Unilever, in 1961. By the year 2000, the firm ranked first and second, respectively, in income from frozen novelties and ice cream in the United States. Globally, Unilever's ice cream brands include Wall's, Streets, HB, Algida, Miko, Frisko, Langnese, and several others, and their most popular product names include Carte d'Or, Cornetto, Magnum, Solero, and Vienetta.

In 1928, William Dreyer, who had celebrated his arrival on a German ship in 1906 by making ice cream, joined with Joseph Edy, a confectioner, to found the Grand Ice Cream Company in Oakland, CA. Dreyer, in 1929, added walnuts and bite-sized marshmallows, cut from large ones with his wife's sewing shears, to make the first batch of rocky road ice cream. William Dreyer, Jr. assumed leadership of the firm in 1953 and then sold it to key officers in 1963. Under the leadership of T. Gary Rogers and William F. Cronk, who bought the company in 1977, Dreyer's expanded from the Western states to states east of the Rocky Mountains where the brand was named Edy's Grand Ice Cream in honor of the cofounder. In 1981, the firm went public and began a direct-to-store delivery network. Expansion through licensing agreements added the names Starbucks Coffee Company, M&M Mars®, and Godiva Chocolatier, Inc. to selected product labels. The firm began global sales in 1992 and became the leading marketer of packaged ice cream in the United States

in 1994. In 2002, Nestlé purchased a controlling interest in Dreyer's Grand Ice Cream Inc. and took full control in 2006, which also gave them the rights to the manufacture of Häagen-Dazs products in North America. Nestlé had previously purchased Carnation in the USA in 1985. Globally, Nestlé mostly sells ice cream under its own name, but its other ice cream brands include Delta (Greece), Peters (Australia), Hjem-Is (Scandinavia), Mövenpick, and many others.

In 1945, Irving Robbins opened the Snowbird Ice Cream Store in Glendale, CA, offering 21 flavors. His brother-in-law, Burt Baskin, soon opened an ice cream store called Burtons. The next year the two competitors became partners and opened a chain of six stores under the name Baskin-Robbins. Nine years later they adopted the "31" Baskin-Robbins logo and embarked on a nationwide franchise program. London-based J. Lyons & Co., Ltd. (later Allied Domecq) purchased Baskin-Robbins in 1973 and began expansion internationally in 1974. As part of Dunkin Brands, they were acquired by a group of private equity firms in 2006. Today, they have more than 5,800 retail locations, 2,800 of which are located in the United States. Baskin-Robbins sells ice cream in over 30 countries. Manufacture is either done by corporate locations or through co-packing arrangements.

The founders of Dairy Queen, "Grandpa" and Alex McCullough, father and son, respectively, were operators of an ice cream mix plant in Kankakee, IL. In 1938, they persuaded a retailer to run a 10-cent "all-you-can-eat" trial of a new soft-frozen dessert at his walk-in ice cream store. Within 2 h he had dished out more than 1,600 servings of the new dessert. In 1939, Alex McCullough persuaded Stoelting Brothers to perfect and manufacture a soft serve freezer originally designed by Harry M. Oltz of Hammond, Indiana. The first Dairy Queen store was started in Joliet, IL in 1940. Numbers of Dairy Queen stores exploded from about 100 in 1947 to 1,446 in 1950. The first Dairy Queen store opened in Canada in 1953. The "Dilly" Bar had its debut from Dairy Queen in 1955. Dairy Queen opened its first store in Japan in 1972 and in the Middle East in 1979. As of 2010, Dairy Queen had more than 5,700 stores in 19 countries, including 652 locations outside the United States and Canada, being one of the largest soft serve franchises in the world.

Häagen-Dazs was founded by Reuben Mattus in the Bronx, New York, in 1961, after having worked in his mother's ice cream business for several years before. He devised the name to reflect old-world traditions. His products expanded from New York City to the US East Coast and across the USA by 1973. In 1976, his daughter Doris opened the first Häagen-Dazs retail store. Pillsbury purchased the Häagen-Dazs company from Mattus in 1983 and General Mills bought Pillsbury in 2001. Thus General Mills now manufactures and markets Häagen-Dazs worldwide, although as a result of a previous arrangement with Dreyer's, when Nestlé purchased Dreyer's in 2002, they obtained the rights to the manufacture and marketing of Häagen-Dazs products in North America under license from General Mills.

Ben Cohen and Jerry Greenfield met in 1963 while in the seventh grade. Fifteen years later they opened their first Ben and Jerry's homemade ice cream shop in a renovated gasoline station in Burlington, Vermont. From these humble beginnings, the company grew to multinational prominence and was purchased in 2000 by Unilever, who continues to operate it separately from their other ice cream companies.

The many areas of progress reviewed in the preceding discussion, as well as many others too numerous to cite, have been made possible largely because of advances in transportation, general availability of electricity and, consequently, of refrigeration, improved packaging, and improved qualities of ingredients, not the least of which are those made from milk. Modern automated, high-volume operations provide a plentiful supply of ice cream in a wide variety of fat contents, flavors, packages, and prices. Novelty manufacturers produce thousands of items of many different types per minute. Specialty producers, often at the retail store level, produce ice cream cakes, pies, and molded items. Since its earliest beginnings, the ice cream trade has become big business.

Overview of Ice Cream Composition and Manufacture

Frozen dairy dessert mixes generally contain seven categories of ingredients: fat (dairy or nondairy), milk solids-not-fat (the principal source of protein), sweeteners, stabilizers, emulsifiers, water, and flavors. Once whipped and frozen, air becomes another important component. The frozen dairy desserts industry is largely represented by ice cream but nevertheless is highly segmented according to composition. Table 1.7 shows the compositional range of typical mix components for a number of frozen dessert products.

Dairy and other ingredients used to supply mix components are chosen on the basis of availability, cost, and expected quality. Fat derived from milk ingredients (cream or butter) or from nondairy fats that are typically solid at refrigerated temperature (coconut, palm, or palm kernel oil) provides texture and structure.

The milk solids-not-fat (MSNF) ingredients contain the lactose, casein and whey proteins, minerals (ash), vitamins, and other minor components from milk, although the ratio of these may be altered by the type of dairy-derived ingredient that is selected (e.g., whole milk protein vs. whey protein). Proteins contribute much to the development of structure in ice cream, including emulsification, whipping, and water holding capacity. Emulsification properties of proteins in the mix arise from their adsorption to fat globules at the time of homogenization. Whipping properties of proteins in ice cream contribute to the formation of the initial air bubbles in the mix. The water holding capacity of proteins leads to enhanced viscosity in the mix, which imparts a beneficial body to the ice cream, increases the meltdown time of ice cream, and contributes to reduced iciness.

In addition to providing sweetness, sweeteners improve the texture and palatability of the ice cream and enhance flavors. Their ability to lower the freezing point of a solution imparts a measure of control over the temperature-hardness relationship. The sweeteners (including lactose from the MSNF component) must be balanced to achieve the proper solids content, the appropriate sweetness level, and a satisfactory degree of hardness.

Ice cream stabilizers are a group of ingredients (usually polysaccharides such as guar, locust bean gum, carboxymethyl cellulose, and xanthan) that produce

Table 1.7 Approximate composition (% by wt.) of commercial frozen desserts by formulation category

Group	Milk fat	Milk solids-not-fat	Sweeteners[a]	Stabilizers[b] and emulsifiers	Total solids
Nonfat ice cream	<0.5	12–14	18–22	1.0	28–32
Low-fat ice cream	2–5	12–14	18–21	0.8	28–32
Light ice cream	5–7	11–12	18–20	0.5	30–35
Reduced-fat ice cream	7–9	10–12	18–19	0.4	32–36
Economy ice cream	10	10–11	15–17	0.4	35–36
Standard ice cream	10–12	9–10	14–17	0.2–0.4	36–38
Premium ice cream	12–14	8–10	13–16	0.2–0.4	38–40
Superpremium ice cream	14–18	5–8	14–17	0–0.2	40–42
Frozen yogurt: regular	3–6	9–13	15–17	0.5	30–36
Frozen yogurt: nonfat	<0.5	9–14	15–17	0.6	28–32
Sherbet	1–2	1–3	22–28	0.4–0.5	28–34

[a]Includes sucrose, glucose, corn syrup solids, maltodextrins, polydextrose, and other bulking agents, some of which contribute little sweetness

[b]Includes ingredients such as locust bean gum, guar gum, carrageenan, cellulose gum, and cellulose gel, as stabilizers, and also mono- and diglycerides and polysorbate 80, as emulsifiers

smoothness in body and texture, retard or reduce ice and lactose crystal growth during storage (or mask the effects of crystal growth), especially during periods of temperature fluctuation, known as heat shock, and provide uniformity to the product and resistance to melting. Their function is mainly through their interactions with water. Emulsifiers (mono- and diglycerides and sorbitan esters, such as polysorbate 80) are sometimes integrated with the stabilizers in proprietary blends, but their function and action is very different from the stabilizers. They are used to improve whipping quality of the mix, produce a drier ice cream to facilitate molding, fancy extrusion, and novelty product manufacture, provide smoother body and texture in the finished product, and produce a product with good stand-up properties and melt resistance. Their function is related to their activity at the air/serum and fat/serum interfaces. In some formulations, eggs also provide similar emulsifying properties.

Frozen dairy dessert products are all consumed in the frozen state and rely on a concomitant freezing and whipping process to establish the desired structure and texture. The manufacturing process for most of these products is similar and involves the preparation of a liquid mix; whipping and freezing this mix dynamically under high shear to a soft, semi-frozen slurry; incorporation of flavoring ingredients to this partially frozen mix; packaging or shaping (as in the case of "novelty" or "impulse" products) the product; and further freezing (hardening) of the product under static, quiescent conditions (Fig. 1.2). The liquid mix is prepared by blending the desired ingredients, followed by pasteurization (batch or continuous), homogenization, and cold aging. Batch pasteurization is very common due to the ease of ingredient blending. Scraped-surface freezers are used for the first freezing step (which incorporates air and produces small, discrete ice crystals, typically at −5 °C). Continuous freezers dominate the medium- to large-scale processing industry, while batch freezers are limited to small-scale processors, retailers, including restaurants, and product