Innovations in Agriculture 2023, 6:01-07
www.innovationsagriculture.com

ISSN: 2617-1295
DOI: https://doi.org/10.25081/ia.2023-12

Review Article

Rheology of ice cream: From fundamentals to applications

Pavel Rout[1*], Shreya Saha[2]

[1]*Dairy Chemistry Division, ICAR-National Dairy Research Institute, Karnal, Haryana 132001, India*

[2]*Dairy Microbiology Division, ICAR-National Dairy Research Institute, Karnal, Haryana 132001, India*

*Corresponding Author, Email: pavel.rout@gmail.com

ARTICLE INFO

Received: August 12, 2023
Revised: September 15, 2023
Accepted: September 16, 2023
Published: September 17, 2023

Keywords:

Ice-cream; Rheological property; Textural property; Sensory property

ABSTRACT

Frozen desserts, including ice cream and related products, have captivated consumer palates for centuries due to their unique combination of taste, texture, and temperature. The complex interplay between ingredients, processing techniques, and the inherent rheological behaviour of these confections has drawn the attention of scientists, engineers, and food technologists alike. Beginning with fundamental insights into the molecular interactions and phase transitions during freezing and storage, the review elucidates the evolving structure-property relationships that define the viscoelastic behaviour of frozen dessert matrices. By dissecting the role of key ingredients, additives, and processing techniques, this article provides a cohesive framework for tailoring the rheological profiles of frozen desserts to achieve desired sensory experiences and stability. Cutting-edge analytical methods, including dynamic mechanical analysis and microstructural imaging, are discussed in the context of their contributions to characterizing and predicting rheological behaviour. The review also highlights practical applications arising from this improved understanding, such as optimized manufacturing processes, enhanced quality control, and the potential to develop novel frozen dessert products with superior texture and flavour delivery. Bridging the gap between scientific insight and industrial practice, this article serves as a valuable resource for researchers, food technologists, and practitioners seeking to advance frozen dessert technology while ensuring product consistency and consumer satisfaction.

INTRODUCTION

Ice cream is a popular dessert enjoyed by people of all ages worldwide. Its unique texture, creamy mouthfeel, and flavour make it one of the most loved treats. However, creating the perfect texture and mouthfeel of ice cream is more than just mixing a few ingredients together. It is an intricate process that involves understanding the science behind its rheology. The rheology of ice cream refers to the study of its flow and deformation properties, which ultimately determine its texture, consistency, and sensory experience [1]. Understanding the rheology of ice cream is essential for the production of high-quality products that meet consumers' expectations and preferences.

Ice cream is a complex food system made up of water, fat, sugar, and protein, which are blended together in specific proportions and subjected to a freezing process. The resulting product is a heterogeneous mixture consisting of air bubbles, fat globules, ice crystals, and a continuous phase of unfrozen water, sugars, and other solids. How these components interact and behave under different conditions and processing steps determines the rheological properties of ice cream [1].

The rheology of ice cream is a critical aspect of its production and quality control. Viscosity, yield stress, thixotropy, and viscoelasticity are some of the rheological properties that determine the texture and mouthfeel of ice cream. Viscosity refers to the resistance of a liquid to flow. Yield stress is the minimum stress required to initiate flow in a non-flowing material. Thixotropy refers to the time-dependent decrease in the viscosity of a material under constant stress [2]. Viscoelasticity is a material property that exhibits viscous and elastic behaviour, depending on the deformation rate.

Factors such as temperature, overrun, stabilizers, emulsifiers, and storage conditions can affect the rheology of ice cream. Temperature influences the rate of ice crystal formation and size distribution, affecting ice cream's overall texture [3]. Overrun, the amount of air incorporated into ice cream during the freezing process can affect its volume and consistency. Stabilizers and emulsifiers can improve the stability and texture of ice cream. Storage conditions can affect the rate of ice crystal growth, texture and the mouthfeel of ice cream over time [4].

Several methods can be used to measure the rheology of ice cream, including rheometers, texture analyzers, and sensory evaluation. Rheometers measure a material's flow properties under controlled conditions of shear rate, temperature, and time [4]. Texture analyzers measure the mechanical properties of a material, such as hardness, chewiness, and adhesiveness. Sensory evaluation involves trained panelists who assess the texture and mouthfeel of ice cream using a range of sensory attributes.

The rheological properties of ice cream play a vital role in its sensory perception. The balance between viscosity, elasticity, and other rheological properties determines the overall sensory experience of ice cream. Understanding this relationship is essential for producing ice cream that meets consumers' preferences and expectations [5,6]. The rheology of ice cream has numerous applications in its production. Rheological measurements can be used to optimize ice cream recipes and improve quality control during production. Additionally, understanding the rheology of ice cream can inform the development of new products that meet changing consumer preferences and dietary needs.

The rheology of ice cream is essential for producing high-quality products that meet consumers' expectations and preferences. The complex interactions of the components of ice cream and the processing conditions determine its rheological properties, ultimately determining its texture, consistency, and sensory experience. The following articles will delve deeper into the different rheological properties of ice cream and how they affect its sensory perception, production, and quality control.

Composition of ice cream

Ice cream is a complex food system comprising several components, including water, fat, sugar, and protein. Each of these components plays a unique role in determining the rheological properties and sensory characteristics of ice cream.

Water is the most abundant component of ice cream, making up approximately 55-65% of the total weight [8]. Water is responsible for the freezing point depression, which allows the ice cream to be frozen at a temperature lower than 0°C. The presence of water also affects the size, distribution, and shape of ice crystals formed during freezing, which in turn impacts the texture and consistency of ice cream [7].

Fat is another critical component of ice cream, contributing to its rich, creamy mouthfeel and flavour. Fat is usually added as milk fat, cream, or vegetable oils. The fat globules in ice cream are surrounded by a layer of proteins, which help to stabilize the emulsion and prevent the coalescence of the fat globules [10]. The size and distribution of fat globules affect the texture and consistency of ice cream. Smaller fat globules create a smoother, creamier texture, while larger fat globules can produce a course, grainy texture [8,9].

Sugar is added to ice cream to improve its sweetness and texture. Sugar acts as a cryoprotectant, preventing the formation of large ice crystals and reducing the freezing point of water. The type and amount of sugar used can affect the texture and mouthfeel of ice cream. For example, higher sugar levels can result in a softer, smoother texture, while lower levels of sugar can result in a firmer, icy texture [9].

Protein is an essential component of ice cream, contributing to its structure and texture. The two main protein sources in ice cream are milk protein and egg yolk. Milk proteins, such as casein and whey protein, play a vital role in stabilizing the emulsion and preventing ice crystal growth. Egg yolks contain emulsifying agents, such as lecithin, which help to stabilize the emulsion and improve the creaminess of ice cream [8,10].

The proportions of these components can vary depending on the type of ice cream produced. For example, premium ice creams may have a higher fat percentage, while low-fat ice creams may have a higher percentage of protein. The ratio of these components can affect the rheological properties and sensory characteristics of ice cream.

The way in which these components interact during the production of ice cream is also critical. When the ice cream mixture is frozen, the air is incorporated into the mixture, forming air bubbles. This process is known as overrun and can significantly affect the rheological properties and sensory characteristics of ice cream. Higher levels of overrun result in a lighter, fluffier texture, while lower levels of overrun result in a denser, firmer texture [8,11]. The composition of ice cream can be modified to improve its rheological properties and sensory characteristics. For example, stabilizers, such as xanthan gum or carrageenan, can be added to improve the stability and texture of ice cream. Emulsifiers, such as mono- and diglycerides, can be added to improve the creaminess and stability of ice cream. Additionally, using alternative sweeteners, such as stevia or erythritol, can affect the sweetness and texture of ice cream. Understanding the role of each component and how they interact during the production of ice cream is essential for producing high-quality products that meet consumer expectations and preferences.

Rheological properties of ice cream

Rheology is the study of the flow and deformation of matter. In the case of ice cream, rheological properties describe how it behaves under stress and strain, such as when it is scooped, eaten, or processed. Understanding the rheological properties of ice cream is essential for developing products that meet consumer preferences and expectations [12].

The rheological properties of ice cream can be divided into two categories: structural properties and textural properties [3,12]. Structural properties refer to the way in which the components of ice cream are arranged, while textural properties refer to the sensations experienced by the consumer when consuming ice cream.

Structural properties

The structural properties of ice cream are determined by the way in which its components interact with each other. The structure of ice cream can be described in terms of its phase behaviour, which refers to the way in which the components are distributed within the mixture [9]. Ice cream is a complex mixture of water, fat, sugar, and protein, and each component can exist in different phases. For example, water can exist as ice crystals, free water, or bound water, while fat can exist as a continuous phase or as dispersed globules. The distribution of these components can significantly affect the structure and stability of ice cream. Ice cream can exist in several phases, including a liquid-like phase, a semi-solid phase, and a solid-like phase. The liquid-like phase refers to the free water in ice cream, which is responsible for its flow properties. The semi-solid phase refers to the mixture of fat and protein, which gives ice-cream its shape and structure. The solid-like phase refers to the ice crystals, which provide ice cream with rigidity and firmness [14].

The structure of ice cream is also influenced by the rate of freezing and the degree of agitation during processing. Slow freezing rates and low levels of agitation can result in the formation of large ice crystals, which can lead to a grainy texture. In contrast, fast freezing rates and high levels of agitation can result in the formation of small ice crystals, which create a smoother, creamier texture.

Textural properties

The textural properties of ice cream refer to the sensations experienced by the consumer when consuming ice cream. These properties are influenced by the structural properties of ice cream, as well as the way in which it is processed and stored. The textural properties of ice cream can be described in terms of hardness, viscosity, and elasticity [15]. Hardness refers to the force required to compress or deform ice cream, while viscosity refers to the resistance of ice cream to flow. Elasticity refers to the ability of ice cream to deform under stress and return to its original shape when the stress is released. The textural properties of ice cream can be measured using various techniques, such as texture analysis and rheometry. Texture analysis involves using a probe to compress or deform ice cream [19]. In contrast, rheometry involves the measurement of the flow and deformation of ice cream under controlled stress and strain [15,16].

The textural properties of ice cream can be modified by adjusting the composition of the mixture, the rate of freezing, and the degree of agitation during processing [18]. For example, increasing the fat content of ice cream can result in a softer, creamier texture, while increasing the protein content can result in a firmer, more elastic texture [19].

The rheological properties of ice cream are essential for developing products that meet consumer preferences and expectations. The structural properties of ice cream are influenced by the way in which its components interact with each other, while the textural properties are influenced by the way in which it is processed and stored. By adjusting the composition and processing parameters of ice cream, it is possible to modify its rheological properties and create products that meet specific consumer demands.

Effect of ingredients on rheological properties of ice cream

The rheological properties of ice cream are influenced by the composition of the mixture, particularly the type and amount of its major ingredients, namely fat, sugar, protein, and water. The following section describes the effect of these ingredients on the rheological properties of ice cream.

Fat

Fat is one of the most important ingredients in ice cream, as it contributes to its texture, mouthfeel, and flavour. The fat content of ice cream can range from 10% to 16%, depending on the desired product characteristics. The type of fat used in ice cream also affects its rheological properties [20]. Milk fat, the primary fat source in ice cream, has a unique triacylglycerol structure that can significantly affect the structure and stability of ice cream. Increasing the fat content of ice cream can result in a softer, creamier texture while reducing the fat content can result in a harder, more icy texture. However, high-fat levels can also result in an unstable product, as fat destabilization can lead to the separation of fat globules from the continuous phase [21].

Sugar

Sugar is a key ingredient in ice cream, contributing to its sweetness, texture, and freezing point depression. The sugar content of ice cream can range from 12% to 16%. The type of sugar used in ice cream can also affect its rheological properties. Sucrose, the most common sugar in ice cream, can contribute to its structure and stability by interacting with protein and water. Increasing the sugar content of ice cream can result in a softer, smoother texture while reducing the sugar content can result in a harder, icy texture [17,22]. However, high sugar levels can also create a sticky, gummy texture [22].

Protein

Protein is an essential ingredient in ice cream, as it contributes to its structure, texture, and mouthfeel. The protein content of ice cream can range from 2% to 5%, depending on the desired product characteristics. The type of protein used in ice cream can also affect its rheological properties. Milk proteins, such as casein and whey protein, are the most common proteins used in ice cream, as they can interact with fat and water to form a stable network. Increasing the protein content of ice cream can result in a firmer, more elastic texture while reducing the protein content can result in a softer, more creamy texture. However, high protein levels can also produce a gritty, sandy texture [23,24].

Water:

Water is a critical component of ice cream, as it forms the continuous phase in which fat, sugar, and protein are dispersed. The water content of ice cream can range from 50% to 70%, depending on the desired product characteristics. The type of water used in ice cream can also affect its rheological properties [12]. Bound water, which is water that is physically or chemically bound to other components in ice cream, can affect its structure and stability. Increasing the water content of ice cream can result in a softer, more scoopable texture while reducing the water content can result in a harder, more icy texture. However, high water levels can also result in a product with low viscosity and poor shape retention. So, the rheological properties of ice cream are influenced by the composition of the mixture, particularly the type and amount of its major ingredients[25]. Understanding the effect of these ingredients on the rheological properties of ice cream is essential for developing products that meet consumer preferences and expectations. By adjusting the composition of ice cream, it is possible to modify its rheological properties and create products that meet specific consumer demands.

Effect of processing on rheological properties of ice cream

In addition to its composition, the rheological properties of ice cream are also affected by the processing conditions used during production. The following section describes the effect of processing on the rheological properties of ice cream.

Homogenization

Homogenization is a critical step in the production of ice cream, as it reduces the size of fat globules and promotes the formation of a stable emulsion. Homogenization also affects the rheological properties of ice cream, particularly its viscosity and texture. Increasing the pressure and number of passes used during homogenization can result in a higher degree of fat globule disruption, leading to a smoother, creamier texture [26]. However, excessive homogenization can result in the formation of small fat globules, which can destabilize the product and lead to fat separation [10].

Pasteurization

Pasteurization is a process that is used to destroy microorganisms and reduce the risk of foodborne illness. Pasteurization (72°C for 15 sec) also affects the rheological properties of ice cream, particularly its viscosity and melting behaviour. Increasing the pasteurization temperature and time can result in a higher degree of protein denaturation, leading to a firmer, more elastic texture. However, excessive pasteurization can result in protein coagulation, leading to a gritty, sandy texture [27,28].

Freezing

Freezing is the final step in the production of ice cream, as it converts the mixture into a solid product. Freezing also affects the rheological properties of ice cream, particularly its hardness, melting behaviour, and crystal size [29]. Lowering the freezing temperature and increasing the freezing time can result in a smaller ice crystal size, leading to a smoother, creamier texture. However, excessively low temperatures and long freezing times can result in a product with a hard, icy texture [3].

Overrun

Overrun is the increase in volume that occurs during the freezing of ice cream due to the incorporation of air. Overrun affects the rheological properties of ice cream, particularly its texture, density, and stability [30]. Increasing the overrun can result in a lighter, fluffier texture, but excessive overrun can result in a product with low viscosity and poor shape retention. Hence, the processing conditions used during the production of ice cream can significantly affect its rheological properties. By adjusting the processing conditions, it is possible to modify the rheological properties of ice cream and create products that meet specific consumer demands. However, it is important to optimize processing conditions to achieve the desired product characteristics while maintaining product stability and quality [31].

Effect of freezing and storage conditions on rheological properties of ice cream

Freezing and storage conditions can significantly affect the rheological properties of ice cream [32]. The following section discusses the effects of freezing and storage conditions on the rheological properties of ice cream.

Freezing rate

The freezing rate of ice cream can affect its microstructure and, therefore, its rheological properties. A slower freezing rate can lead to the formation of larger ice crystals, which can cause the ice cream to be grainy and icy. On the other hand, a faster freezing rate can lead to the formation of smaller ice crystals, which can improve the texture and mouthfeel of the ice cream [13].

Ice cream storage temperature

The storage temperature of ice cream can significantly affect its rheological properties. At low temperatures, the viscosity of ice cream can increase due to the concentration of the dispersed phase and the formation of a more rigid network structure. At higher temperatures, the viscosity of ice cream can decrease due to the melting of the ice crystals and the destabilization of the network structure [33].

Storage time

The storage time of ice cream can also affect its rheological properties. Over time, ice cream can undergo changes in its microstructure and rheological properties due to a range of physical and chemical phenomena, such as ice recrystallization, protein denaturation, fat destabilization, and syneresis. These changes can lead to a decrease in the quality and stability of ice cream [34].

Ice crystal size

The size of ice crystals in ice cream can also affect its rheological properties. Larger ice crystals can cause ice cream to be gritty and icy, while smaller ice crystals can improve the smoothness and mouthfeel of the product. Ice crystal growth can be controlled through the use of stabilizers and the optimization of the freezing and storage conditions.

Overrun

Overrun refers to the increase in the volume of ice cream due to the incorporation of air during the freezing process. Overrun can affect the rheological properties of ice cream, particularly its texture and melting behaviour. High overrun can result in a less dense and more aerated ice cream with a faster melting rate. Low overrun can result in a denser and more viscous ice cream with a slower melting rate [35].

Hence, the rheological properties of ice cream can be significantly affected by freezing and storage conditions. The freezing rate, storage temperature, storage time, ice crystal size, and overrun can all impact the microstructure and rheological properties of ice cream [36].

Effect of additives on rheological properties of ice cream

Additives are commonly used in the production of ice cream to modify its rheological properties and improve its sensory attributes. The following section discusses the effect of some of the commonly used additives on the rheological properties of ice cream [3,9,22].

Emulsifiers

Emulsifiers are used in ice cream production to promote the formation of a stable emulsion between the fat and water phases. Emulsifiers can affect the rheological properties of ice cream, particularly its viscosity and stability. Emulsifiers such as mono- and diglycerides can increase the viscosity of the ice cream mix by reducing the mobility of the water molecules and promoting the formation of a more rigid network structure [37]. Emulsifiers can also improve the stability of ice cream by reducing the rate of coalescence and flocculation of fat globules during storage [22,23].

Stabilizers

Stabilizers are used in ice cream production to modify its rheological properties and improve its stability. Stabilizers can affect the rheological properties of ice cream, particularly its viscosity, melting behaviour, and texture. Stabilizers such as carboxymethyl cellulose (CMC) and locust bean gum can increase the viscosity of the ice cream mix by increasing the concentration of the dispersed phase and promoting the formation of a more rigid network structure. Stabilizers can also improve the melting behaviour of ice cream by reducing the rate of ice crystal growth and delaying the onset of melting [22,37].

Sweeteners

Sweeteners are used in ice cream production to modify its sensory properties and improve its shelf life. Sweeteners can affect the rheological properties of ice cream, particularly its freezing point depression and texture. Sweeteners such as sucrose and corn syrup can depress the freezing point of ice cream, resulting in a softer, more scoopable texture. Sweeteners can also increase the viscosity of the ice cream mix by increasing the concentration of the dispersed phase and promoting the formation of a more rigid network structure [22,38].

So, the rheological properties of ice cream can be modified by adding various additives during production. Emulsifiers can promote a more stable emulsion, stabilizers can increase viscosity and improve stability, and sweeteners can affect freezing point and texture. By carefully selecting and using these additives, ice cream manufacturers can create products that meet specific consumer demands and maintain high quality and stability.

The relationship between rheology and sensory perception

Rheological properties play a crucial role in determining the sensory experience of ice cream. Sensory perception refers to the experience of the consumer's senses, including the taste, texture, aroma, and appearance of ice cream. Rheological properties are key factors in determining the texture and mouthfeel of ice cream. The following sections discuss the relationship between rheological properties and sensory perception and the importance of balancing these properties to create the desired sensory experience [37–39].

How rheological properties affect the sensory experience of ice cream

Texture and mouthfeel

Texture and mouthfeel are important attributes in the sensory perception of ice cream. The texture is described as the physical characteristics of the ice cream, such as creaminess, smoothness, and thickness. At the same time, the mouthfeel is the sensation of the ice cream in the mouth, such as the creaminess, melting behaviour, and viscosity. Rheological properties, such as viscosity, yield stress, and elasticity, play a crucial role in determining the texture and mouthfeel of ice cream. For example, a higher viscosity can lead to a creamier texture and slower melting behaviour, while a lower viscosity can result in a smoother and faster-melting ice cream [37].

Melting behaviour

The melting behaviour of ice cream can also affect the sensory experience. The rate of melting, as well as the perception of creaminess during melting, is affected by the rheological properties of ice cream. A slower melting rate can lead to a more enjoyable sensory experience, as it allows the consumer to savour the flavours of the ice cream for a longer period [37]. Furthermore, a creamier melting sensation is often perceived as more enjoyable by consumers.

Flavour release

The flavour release of ice cream is also affected by its rheological properties. Rheological properties can influence the flow behaviour and adherence of the ice cream to the tongue, affecting the perception of flavour intensity and duration. The right rheological properties can create a more intense and longer-lasting flavour experience, leading to a more enjoyable sensory experience [37,38].

The importance of balancing rheological properties to create the desired sensory experience

Balancing rheological properties

The right balance of rheological properties is crucial in creating the desired sensory experience of ice cream. For example, the viscosity should be high enough to create a creamy texture but not so high that it affects the melting behaviour. Similarly, the elasticity should be high enough to prevent ice cream from dripping, but not so high that it affects the sensory experience of the product. The correct balance of rheological properties can enhance the sensory experience, creating a more enjoyable product.

Stabilizers

Stabilizers are often used in ice cream production to balance rheological properties and improve the sensory experience. Stabilizers can help control the size of ice crystals, prevent ice recrystallization, and control viscosity and elasticity. They can also improve the melting behaviour of ice cream, resulting in a more enjoyable sensory experience [11,37].

Consumer preferences

Finally, it is essential to consider consumer preferences when creating ice cream products. The desired rheological properties and sensory experience can vary depending on the target consumer. For example, children may prefer a less viscous and faster-melting ice cream, while adults may prefer a creamier texture and slower melting behaviour. Therefore, it is essential to balance the rheological properties to meet the needs and expectations of the target consumer.

The rheological properties of ice cream play a crucial role in determining the sensory experience of the product. The texture, mouthfeel, melting behaviour, and flavour release are all influenced by the rheological properties of ice cream [11]. The correct balance of these properties is crucial in creating the desired sensory experience, and stabilizers are often used to achieve this. Furthermore, consumer preferences should be considered when creating ice cream products to meet needs and expectations.

Applications of rheology in ice cream production

Rheology, the study of the deformation and flow of matter, has several applications in ice cream production. In the manufacturing process, it is essential to understand the rheological properties of the ice cream mix and the final product to optimize recipes, ensure quality control, and develop new products [31]. The following sections discuss the three main applications of rheology in ice cream production.

Optimization of recipes

The rheological properties of the ice cream mix are crucial in optimizing the recipe. A well-designed recipe should produce a product with the desired texture, mouthfeel, and flavour. Rheological measurements, such as viscosity, yield stress, and elastic modulus, can provide insights into the behaviour of the ice cream mix during processing, such as churning, aging, and freezing.

Viscosity measurements, for instance, can be used to determine the resistance of the mix to flow during processing. High viscosity may lead to difficulties in mixing and pumping, while low viscosity may result in a thin and runny product. The use of stabilizers, such as carrageenan, xanthan gum, or gelatine, can affect the viscosity of the mix and improve the stability and texture of the final product [11].

Yield stress is another crucial rheological property that can affect the behaviour of the mix during processing. The yield stress is the amount of stress required to start the flow of the mix. Understanding the yield stress can help optimize processing parameters, such as the agitation rate and freezing temperature, to achieve the desired texture and mouthfeel [37].

Quality control

Rheological measurements are also essential in ensuring the quality of the final product. In particular, the consistency and texture of the ice cream are critical quality attributes. The consistency of product should be consistent from batch to batch, and rheological measurements can be used to ensure that the product meets the desired specifications. For example, an ice cream product with low viscosity may indicate that it has undergone temperature abuse. In contrast, a high viscosity may indicate the presence of partially coalesced fat droplets [46]. A high-yield stress may indicate poor emulsification, while a low-yield stress may indicate the presence of a large amount of destabilized protein. Rheological measurements, such as shear modulus, loss modulus, and tan delta, can provide insights into the structural and mechanical properties of the product. These measurements can help in identifying changes in the product due to formulation or processing changes, as well as predicting the shelf life of the product.

Development of new products

Rheology is also crucial in the development of new ice cream products. It can help in understanding the behaviour of new ingredients, such as fat replacers, sweeteners, and flavourings, and their effects on the texture, mouthfeel, and flavour of the product. Rheological measurements can also help in the design of new processing techniques, such as the use of ultra-high-pressure homogenization or high-pressure freezing. These techniques can affect the texture and stability of the final product, and rheological measurements can provide insights into the behaviour of the product during these processes [38]. Furthermore, rheology can be used to predict the sensory attributes of the product, such as creaminess, smoothness, and melting behaviour. This information can be used to optimize the recipe and processing parameters to create the desired sensory experience for the consumer. So, rheology has several applications in ice cream production, including the optimization of recipes, quality control, and the development of new products [38]. Understanding the rheological properties of the ice cream mix and the final product is essential in ensuring the quality and consistency of the product. Furthermore, rheology can be used to create new and innovative products that meet the needs and preferences of consumers.

Summary and conclusion

The article started with a discussion of the importance of rheology in ice cream production, followed by a description of the rheological properties of ice cream, including viscosity, yield stress, and viscoelasticity. The article then explored the effects of ingredients, such as fat, sugar, and stabilizers, on the rheological properties of the ice cream mix and the final product. It also discussed the relationship between rheology and sensory perception, highlighting the importance of balancing rheological properties to create the desired sensory experience. Finally, the article discussed the applications of rheology in ice cream production, including the optimization of recipes, quality control, and the development of new products.

In conclusion, the rheology of ice cream is a complex but critical area of research that has significant implications for ice cream production, quality control, and product development. This article has provided an overview of the key concepts and techniques involved in the measurement and interpretation of the rheological properties of ice cream.

Future directions for research in the rheology of ice cream

The rheology of ice cream is a rapidly evolving field of research with several exciting opportunities for future investigation. One future direction is to develop more sophisticated models that can accurately predict the rheological properties of ice cream, considering the effects of the various ingredients and processing parameters. Another future direction is to explore the relationship between rheology and the microstructure of ice cream, which can provide insights into the stability and textural properties of the product. Furthermore, there is a need to investigate the effects of emerging ingredients, such as plant-based alternatives to dairy, on the rheology and sensory properties of ice cream.

Overall, the rheology of ice cream is a fascinating and challenging area of research that requires interdisciplinary collaboration between food scientists, physicists, and engineers. The advances in this field will not only help in improving the quality and consistency of ice cream products but also in developing new and innovative products that meet the changing needs and preferences of consumers.

REFERENCES

1. Karaca OB, GÜVEN M, Yasar K, Kaya S, Kahyaoglu T. The functional, rheological and sensory characteristics of ice creams with various fat replacers. Int J of Dairy Tech. 2009;62(1):93–9.
2. Pon SY, Lee WJ, Chong GH. Textural and rheological properties of stevia ice cream. Int Food Res J. 2015;22(4).
3. Kurt A, Atalar I. Effects of quince seed on the rheological, structural and sensory characteristics of ice cream. Food Hydrocoll. 2018;82:186–95.
4. Freire DO, Wu B, Hartel RW. Effects of structural attributes on the rheological properties of ice cream and melted ice cream. J Food Sci. 2020;85(11):3885–98.
5. Kurt A, Cengiz A, Kahyaoglu T. The effect of gum tragacanth on the rheological properties of salep based ice cream mix. Carbohydr Polym. 2016;143:116–23.
6. Balthazar CF, Silva HLA, Cavalcanti RN, Esmerino EA, Cappato LP, Abud YKD, et al. Prebiotics addition in sheep milk ice cream: A rheological, microstructural and sensory study. J Funct Foods. 2017;35:564–73.
7. Cavender GA, Kerr WL. Microfluidization of full-fat ice cream mixes: Effects on rheology and microstructure. J Food Process Eng. 2020;43(2):e13350.
8. Kilara A, Chandan RC. Ice cream and frozen desserts. Dairy Proces Qual Assur. 2015;367–96.
9. El Owni OAO, Zeinab KK. Chemical composition of ice cream produced in Khartoum state, Sudan. Pak J Nutr. 2009;8(2):158–60.
10. Goff HD. Colloidal aspects of ice cream—a review. Int Dairy J. 1997;7(6–7):363–73.
11. Marshall RT, Goff HD, Hartel RW. Composition and Properties. In: Ice Cream. Boston, MA: Springer US; 2003. p. 11–54.
12. Marshall RT. ICE CREAM | methods of manufacture. In: Encyclopedia of Food Sciences and Nutrition. Elsevier; 2003. p. 3221–7.
13. De Souza J, Costa M De R, Rensis D, Sivieri C. Ice cream: composition, processing and addition of probiotic. Alimentos e Nutrição. 2010;21(1):155–65.
14. Arbuckle WS. Ice cream. Springer; 2013 Mar 9.
15. Aboulfazli F, Baba AS, Misran M. The rheology and physical properties of fermented probiotic ice creams made with dairy alternatives. Int J Food Eng. 2015;11(4):493–504.
16. Adapa S, Schmidt KA, Jeon IJ, T. J. HERALD, Flores RA. Mechanisms of ice crystallization and recrystallization in ice cream: A review. Food Rev Int. 2000;16(3):259–71. http://dx.doi.org/10.1081/fri-100100289
17. Bolliger S, Goff HD, Tharp BW. Correlation between colloidal properties of ice cream mix and ice cream. Int Dairy J. 2000;10(4):303–9.
18. Kealy T. Application of liquid and solid rheological technologies to the textural characterization of semi-solid foods. Food Res Int. 2006;39(3):265–76. http://dx.doi.org/10.1016/j.foodres.2005.07.01
19. Liu X, Sala G, Scholten E. Structural and functional differences between ice crystal-dominated and fat network-dominated ice cream. Food Hydrocoll. 2023;138(108466):108466. http://dx.doi.org/10.1016/j.foodhyd.2023.108466.
20. Leahu A, Ropciuc S, Ghinea C. Plant-based milks: Alternatives to the manufacture and characterization of ice cream. App Sci. 2022;12(3):1754.
21. Sherman P. A texture profile of foodstuffs based upon well-defined rheological properties. J Food Sci. 1969;34(5):458–62.
22. Hartel RW. Ice crystallization during the manufacture of ice cream. Trends Food Sci Technol. 1996;7(10):315–21. http://dx.doi.org/10.1016/0924-2244(96)10033-9.
23. Mahdian E, Karazhian R. Effects of fat replacers and stabilizers on rheological, physicochemical and sensory properties of reduced-fat ice cream. J Agric Sci Tech. 2013;15(6):1163–74.
24. Syed QA, Anwar S, Shukat R, Zahoor T. Effects of different ingredients on texture of ice cream. J Nutr Health Food Eng. 2018;8(6):422–35.
25. Cheng J, Ma Y, Li X, Yan T, Cui J. Effects of milk protein-polysaccharide interactions on the stability of ice cream mix model systems. Food Hydrocoll. 2015;45:327–36.
26. Milani J, Maleki G. Hydrocolloids in Food Industry. In: Food Industrial Processes - Methods and Equipment. InTech; 2012.
27. Innocente N, Biasutti M, Venir E, Spaziani M, Marchesini G. Effect of high-pressure homogenization on droplet size distribution and rheological properties of ice cream mixes. J Dairy Sci. 2009;92(5):1864–75. http://dx.doi.org/10.3168/jds.2008-1797
28. Vélez-Ruiz JF, Barbosa Cánovas GV. Rheological properties of selected dairy products. Crit Rev Food Sci Nutr. 1997;37(4):311–59. http://dx.doi.org/10.1080/10408399709527778.
29. Bazmi A, Relkin P. Effects of processing conditions on structural and functional parameters of whipped dairy emulsions containing various fatty acid compositions. J Dairy Sci. 2009;92(8):3566–74.

30. Muse MR, Hartel RW. Ice cream structural elements that affect melting rate and hardness. J Dairy Sci. 2004;87(1):1–10. http://dx.doi.org/10.3168/jds.S0022-0302(04)73135-5.
31. Ghaderi S, Mazaheri Tehrani M, Hesarinejad MA. Qualitative analysis of the structural, thermal and rheological properties of a plant ice cream based on soy and sesame milks. Food Sc Nutr. 2021;9(3):1289–98. http://dx.doi.org/10.1002/fsn3.2037.
32. Wildmoser H, Scheiwiller J, Windhab EJ. Impact of disperse microstructure on rheology and quality aspects of ice cream. Lebenson Wiss Technol. 2004;37(8):881–91. http://dx.doi.org/10.1016/j.lwt.2004.04.006.
33. Soukoulis C, Lebesi D, Tzia C. Enrichment of ice cream with dietary fibre: Effects on rheological properties, ice crystallisation and glass transition phenomena. Food Chem. 2009;115(2):665–71. http://dx.doi.org/10.1016/j.foodchem.2008.12.070.
34. Alvarez VB, Wolters CL, Vodovotz Y, Ji T. Physical properties of ice cream containing milk protein concentrates. J Dairy Sci. 2005;88(3):862–71. http://dx.doi.org/10.3168/jds.S0022-0302(05)72752-1.
35. Salem SA, Fardous M, El-Rashody MG. Effect of camel milk fortified with dates in ice cream manufacture on viscosity, overrun, and rheological properties during storage period. Food Nutr Sci. 2017;8(05):551. http://dx.doi.org/10.4236/fns.2017.85038.
36. Freire DO, Wu B, Hartel RW. Effects of structural attributes on the rheological properties of ice cream and melted ice cream. J Food Sci. 2020;85(11):3885–98. http://dx.doi.org/10.1111/1750-3841.15486.
37. Ludvigsen HK. Application of emulsifiers in dairy and ice cream products. In: Emulsifiers in Food Technology. Chichester, UK: John Wiley & Sons, Ltd; 2014. p. 297–308.
38. Adapa S, Dingeldein H, Schmidt KA, T.J. Herald. Rheological properties of ice cream mixes and frozen ice creams containing fat and fat replacers. J Dairy Sci. 2000;83(10):2224–9. http://dx.doi.org/10.3168/jds.s0022-0302(00)75106-x.
39. Conforti FD. Effect of fat content and corn sweeteners on selected sensory attributes and shelf stability of vanilla ice cream. Int J Dairy Technol. 1994;47(2):69–75. http://dx.doi.org/10.1111/j.1471-0307.1994.tb01275.x.
40. Fonseca FGA, Esmerino EA, Filho ERT, Ferraz JP, da Cruz AG, Bolini HMA. Novel and successful free comments method for sensory characterization of chocolate ice cream: A comparative study between pivot profile and comment analysis. J Dairy Sci. 2016;99(5):3408–20. http://dx.doi.org/10.3168/jds.2015-9982.
41. Asres AM, Woldemariam HW, Gemechu FG. Physicochemical and sensory properties of ice cream prepared using sweet lupin and soymilk as alternatives to cow milk. Int J Food Prop. 2022;25(1):278–87. http://dx.doi.org/10.1080/10942912.2022.2032733.
42. Doyennette M, Aguayo-Mendoza MG, Williamson AM, Martins SI, Stieger M. Capturing the impact of oral processing behaviour on consumption time and dynamic sensory perception of ice creams differing in hardness. Food Qual Prefer. 2019;78(103721):103721. http://dx.doi.org/10.1016/j.foodqual.2019.103721.
43. Selway N, Stokes JR. Soft materials deformation, flow, and lubrication between compliant substrates: Impact on flow behavior, mouthfeel, stability, and flavor. Annu Rev Food Sci Technol. 2014;5:373–93. http://dx.doi.org/10.1146/annurev-food-030212-182657.
44. Kokini J, van Aken G. Discussion session on food emulsions and foams. Food Hydrocoll. 2006;20(4):438–45. http://dx.doi.org/10.1016/j.foodhyd.2005.10.003.
45. Rizzo G, Masic U, Harrold JA, Norton JE, Halford JCG. Coconut and sunflower oil ratios in ice cream influence subsequent food selection and intake. Physiol Behav. 2016;164:40–6. http://dx.doi.org/10.1016/j.physbeh.2016.05.040.46.
46. Andrew RA. Biopolymer interactions: implications in ice cream mix. University of Guelph; 2003.
47. Landikhovskaya AV, Tvorogova AA. Ice cream and frozen desserts nutrient compositions: current trends of researches. Food Syst. 2021;4(2):74–81. http://dx.doi.org/10.21323/2618-9771-2021-4-2-74-81.