

**UNIVERSIDADE FEDERAL RURAL DO RIO DE JANEIRO
INSTITUTO DE TECNOLOGIA
DEPARTAMENTO DE TECNOLOGIA DE ALIMENTOS
PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIA E TECNOLOGIA
DE ALIMENTOS**

DISSERTAÇÃO

**PRODUÇÃO DE SORVETE DE COCO COM ADIÇÃO DE
BIOMASSA DE BANANA VERDE (*MUSA SP.*) COMO
SUBSTITUTO DE GORDURA**

SHELSEA LUÍS CUAMBE

2025



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SHELSEA LUÍS CUAMBE

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Dra. Maria Ivone Martins Jacintho Barbosa

Dissertação submetida como requisito parcial para obtenção do grau de Mestre em Ciência e Tecnologia de Alimentos, no Programa de Pós-Graduação em Ciência e Tecnologia de Alimentos, área Ciência de Alimentos.

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"Tudo posso, naquele que me fortalece"
Filipenses 4:13

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“We don’t have to do it all alone. We were never meant to.”
Brené Brown

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RESUMO

CUAMBE, Shelsea Luís. **Produção de sorvete de coco com adição de biomassa de banana verde (*Musa sp.*) como substituto de gordura**. 2025. p. 99. Dissertação. (Mestrado em Ciência e Tecnologia de Alimentos). Instituto de Tecnologia, Departamento de Tecnologia de Alimentos, Universidade Federal Rural do Rio de Janeiro, Seropédica/RJ, 2025.

A biomassa de banana verde (BBV) apresenta potencial para aplicação em produtos alimentícios quando o objetivo é reduzir o conteúdo de gordura. Contudo, existem muito poucos estudos que exploram o impacto de sua adição na redução de gordura em sorvetes. A ingestão excessiva de gorduras está associada a doenças crônicas não transmissíveis, como a obesidade. Essas condições de saúde têm impactos significativos e ressaltam a importância de uma abordagem equilibrada e consciente em relação à alimentação. Deste modo, o objetivo deste trabalho foi desenvolver um sorvete de coco com adição de BBV (variedade prata) como um substituto do teor de gordura, bem como avaliar o efeito de sua aplicação sobre as propriedades físico-químicas, microbiológicas e sensoriais. Para tal, foram elaborados dois capítulos, no primeiro, foram explorados os avanços de pesquisas em miméticos de gordura a base de amido e sua aplicação em sorvetes através de uma revisão da literatura. Constatou-se que os miméticos de gordura à base de amido representam uma alternativa promissora para o desenvolvimento de sorvetes com baixo teor de gordura, atendendo à crescente demanda por produtos mais saudáveis. Ademais, os avanços nas técnicas de modificação do amido, como a nanotecnologia e os tratamentos enzimáticos sustentáveis, permitem reproduzir características desejáveis, como cremosidade, textura e estabilidade, que tradicionalmente são proporcionados pelas gorduras. Dentre os diferentes tipos de amido, tem se destacado o amido resistente por seu potencial de reduzir a gordura e oferecer benefícios funcionais, incluindo aumento fibra alimentar. No entanto, ainda existem desafios, como alcançar um equilíbrio entre sabor, custo-benefício e viabilidade industrial. No segundo estudo, foram elaboradas 5 formulações de sorvete (0% BBV; 25% BBV; 50% BBV; 75% BBV; 100% BBV). A biomassa apresentou um alto teor de amido total (15.99 ± 0.78). No sorvete, observou-se que a formulação 25% biomassa não apresentou diferenças significativas em relação à formulação padrão ($p > 0,05$) em todos os atributos sensoriais avaliados, incluindo cor, presença de cristais de gelo na superfície, sabor de coco, doçura, cremosidade, percepção de cristais de gelo na boca, sensação de gordura na boca e capacidade de servir com colher. Entretanto, análises instrumentais indicaram que, a partir de 50% de substituição da gordura, características como dureza, incorporação de ar, cor e doçura foram negativamente afetadas. Por outro lado, verificou-se que maiores concentrações de BBV reduziram a taxa de derretimento do sorvete. Em suma, este estudo reforça o potencial da biomassa de banana verde como um substituto de gordura em sorvetes, possibilitando o desenvolvimento de formulações com menor teor lipídico, além de potenciais vantagens funcionais em comparação aos sorvetes convencionais.

Palavras-chave: Indústria de alimentos. Redução de gordura. Amido resistente. Sorvete

ABSTRACT

CUAMBE, Shelsea Luís. **Production of coconut ice cream with addition of green banana biomass (*Musa sp.*) as a fat replacer**. 2025. p. 99. Dissertation. (Master's degree in food science and technology). Institute of Technology, Department of Food Technology, Federal Rural University of Rio de Janeiro, Seropédica/RJ, 2025.

Green banana biomass (GBB) has potential for application in food products when the objective is to reduce fat content. However, very few studies have explored the impact of its addition on fat reduction in ice creams. Excessive fat intake is associated with chronic diseases, such as obesity. These health conditions have significant impacts and highlight the importance of a balanced and conscious approach to food consumption. Thus, this study aimed to develop a coconut ice cream with the addition of GBB (prata variety) as a fat substitute and to evaluate its effects on the physicochemical, microbiological, and sensory properties. For this purpose, two chapters were developed. The first study explored advancements in starch-based fat mimetics and their application in ice creams through a literature review. It was found that starch-based fat mimetics represent a promising alternative for the development of low-fat ice creams, meeting the growing demand for healthier products. Moreover, advancements in starch modification techniques, such as nanotechnology and sustainable enzymatic treatments, allow for the reproduction of desirable characteristics, such as creaminess, texture, and stability that are traditionally provided by fats. Among the different types of starch, resistant starch has stood out for its potential to reduce fat content while offering functional benefits, including increased dietary fiber intake. However, challenges remain, such as achieving a balance between flavor, cost-effectiveness, and industrial feasibility. In the second study, five ice cream formulations were developed (0% GBB; 25% GBB; 50% GBB; 75% GBB; 100% GBB). The biomass exhibited a high total starch content (15.99 ± 0.78). Regarding the ice cream, it was observed that the 25% biomass formulation showed no significant differences compared to the standard formulation ($p > 0.05$) in all evaluated sensory attributes, including color, presence of ice crystals on the surface, coconut flavor, sweetness, creaminess, perception of ice crystals in the mouth, fat sensation in the mouth, and spoonability. However, instrumental analyses indicated that, from 50% fat replacement onwards, characteristics such as hardness, overrun, color, and sweetness were negatively affected. On the other hand, higher concentrations of GBB reduced the ice cream's melting rate. In summary, this study reinforces the potential of green banana biomass as a fat replacer in ice cream, enabling the development of formulations with lower lipid content while also offering potential functional benefits compared to conventional ice creams.

Keywords: Food industry. Fat reduction. Resistant starch. Ice cream.

PRODUÇÃO CIENTÍFICA

Capítulo	Tema	Periódico	Situação
I	Miméticos de Gordura à Base de Amido em Sorvetes: Tendências Bibliométricas e Aplicações Tecnofuncionais <i>Starch-based Fat Mimetics in Ice Cream: Bibliometric Trends and Techno-functional Applications</i>	Journal of Food Science	Submetido
II	Biomassa de banana verde como mimético de gordura na qualidade físico-química e sensorial do sorvete de coco <i>Green banana biomass as a fat mimetic on the physicochemical and sensory quality of coconut ice cream</i>	-	Não publicado

Ao longo da elaboração da dissertação, foram apresentados resumos em conferências nacionais:

CUAMBE, S. L.; ROCHA, E.; BARBOSA, M. I. M. J. Development of coconut ice cream with green banana biomass (*Musa sp.*): Physicochemical and technological characterization. In: 29º Congresso Brasileiro de Ciência e Tecnologia de Alimentos, Florianópolis, 2024.

CUAMBE, S. L.; BARBOSA, M. I. M. J. Biomassa de banana verde: Um substituto funcional e sustentável de gordura em sorvetes. In: Inova Alimentos, Rio de Janeiro, 2024.

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INTRODUÇÃO GERAL

A indústria de alimentos vem, atualmente, se apresentando como um mercado bastante competitivo e em rápidas mudanças, com destaque para o desenvolvimento e introdução de novos produtos alimentícios aos consumidores. No caso dos alimentos tradicionais com propriedades já conhecidas, o nível de inovação e o impacto da sua aplicação constituem aspectos preponderantes para a aceitação do consumidor.

A demanda de produtos com menor teor de gordura (sobretudo a saturada ou gordura trans), de açúcares ou calorias vem crescendo, ou seja, os consumidores buscam alimentos mais saudáveis e nutritivos. Assim, a adição de novos ingredientes alimentícios com propriedades funcionais que melhorem a saudabilidade e qualidade de vida se torna essencial, para atender à procura desses produtos pelos consumidores.

A biomassa de banana verde (BBV), que é um produto resultante do cozimento de banana nos estágios 1 e 2 de maturação (completamente verde e verde com traços amarelos, respectivamente), tem chamado atenção da indústria alimentícia nos últimos tempos, visto que melhora significativamente a qualidade nutricional dos alimentos aos quais é incorporada. Adicionalmente, a comercialização da banana é limitada pelas perdas pós-colheita, que chegam a atingir 20% do total da produção (Falcomer et al., 2019), por isso, a transformação da banana verde em biomassa pode contribuir para redução dos desperdícios por danos mecânicos gerados após a produção, sendo assim uma alternativa economicamente viável.

Além disso, o consumo da banana verde não é habitual, devido à presença de altas concentrações de compostos fenólicos solúveis, como taninos, responsáveis pelo sabor adstringente e textura firme no fruto, desfavorecendo a aceitação do consumidor. Portanto, a BBV surge como uma boa opção para aproveitamento do seu valor nutricional em diferentes matrizes alimentares.

A banana verde é um fruto de alta qualidade nutricional, pois contém sais minerais, fibras, potássio, vitaminas B1 e B6, β -caroteno e vitamina C. O que a destaca é a presença do amido resistente (AR), um prebiótico usado no desenvolvimento de produtos enriquecidos em fibra, que está diretamente ligado a melhoria das funções metabólicas, ao aperfeiçoamento do perfil lipídico dos alimentos, melhoria da atividade da microbiota intestinal através da redução do pH que promove o crescimento de bactérias benéficas no cólon.

Por conseguinte, a biomassa produzida a partir da banana verde apresenta inúmeras opções de aplicabilidade no desenvolvimento de produtos alimentícios, tais como pães, bolos, biscoitos, massas, maionese, patês, sucos, sorvetes, entre outros produtos. A sua aplicação não interfere significativamente no sabor e odor dos produtos aos quais é adicionada, conferindo-lhe flexibilidade de utilização em preparações doces e salgadas.

No Brasil, o sorvete pertence à classe de gelados comestíveis, e é definido como um produto congelado obtido a partir de uma emulsão de gorduras e proteínas, ou de uma mistura de água e açúcares, podendo ser adicionados de outros ingredientes desde que não descaracterizem o produto (Anvisa, 1999).

O sorvete tem apresentado progressos consideráveis no mercado e na área de laticínios é um dos mais produzidos e consumidos no mundo. Prevê que o mercado global dos sorvetes cresça de US\$ 73,61 bilhões em 2022 para US\$ 104,96 bilhões até 2029 (FBI, 2022). Por outro lado, nos últimos anos a demanda por sobremesas rápidas, saudáveis e funcionais alcançou a indústria do sorvete, ou seja, a presença de propriedades probióticas, prebióticas e/ou antioxidantes tem despertado a atenção dos consumidores. Assim, acredita-se que o número de estabelecimentos que comercializam sorvetes elaborados com formulações que privilegiem ingredientes naturais aumentará nos próximos anos.

A produção de sorvete envolve diversos tipos de receitas ou combinações de ingredientes que desempenham um papel fundamental nas características do produto, dentre os quais a gordura se destaca. Embora baunilha, chocolate e morango sejam os sabores de sorvete

mais consumidos mundialmente, o coco também se destaca, principalmente em regiões tropicais e entre consumidores que buscam alternativas vegetais aos laticínios. No entanto, o sorvete de coco tende a apresentar um teor de gordura elevado, pois, além da gordura presente no leite de coco, sua formulação geralmente inclui a adição de creme de leite ou outras fontes lipídicas para garantir cremosidade e textura. Por isso, reduzir a gordura nesse tipo de sorvete é essencial para equilibrar seu valor calórico.

As gorduras desempenham um papel fundamental ao intensificar o sabor pois veiculam compostos aromáticos, contribuindo para uma experiência sensorial mais rica. Além disso, as gorduras desempenham um papel essencial na melhoria da textura através da criação de uma estrutura que confere suavidade ao produto e atribuem propriedades de fusão desejadas.

Todavia, a ingestão excessiva de gorduras está diretamente associada ao surgimento de doenças crônicas não transmissíveis, como a obesidade. Essas condições de saúde têm impactos significativos e ressaltam a importância de uma abordagem equilibrada e consciente em relação à alimentação. Ademais, a presença de um teor relativamente alto de ácidos graxos saturados na gordura do leite está associada a efeitos negativos à saúde, que podem aumentar o risco de doenças cardiovasculares devido a elevação do nível do colesterol e da lipoproteína de baixa densidade.

O Ministério da Saúde, através da Agência Nacional de Vigilância Sanitária (ANVISA) introduziu mudanças significativas nas normas de rotulagem nutricional, descritas na Resolução da Diretoria Colegiada (RDC) nº 429/20201 e pela Instrução Normativa (IN) nº 75/20202. Desde outubro de 2023, as empresas no Brasil viram-se obrigadas a incluir mais informações nutricionais em seus rótulos, como alertas visuais sobre altos conteúdos de sódio, açúcares adicionados e gorduras saturadas. Ademais, a Organização Mundial da Saúde incentiva o uso de rótulos nutricionais frontais, claros e intuitivos, pois podem não apenas facilitar a escolha de alimentos mais saudáveis, mas também incentivar a reformulação de produtos para atender as demandas de saúde pública.

A biomassa de banana verde apresenta um bom potencial de aplicação em produtos alimentícios, quando o objetivo é reduzir o conteúdo de gordura. Embora estudos anteriores tenham investigado diversos substitutos de gordura na produção de sorvetes, há uma lacuna significativa quanto à aplicação da biomassa de banana verde para esse fim. Assim, há necessidade de desenvolvimento de mais pesquisas para explorar esse ingrediente promissor e para indústria de alimentos.

Deste modo, o objetivo deste trabalho foi desenvolver sorvete de coco com adição de biomassa de banana verde como um substituto do teor de gordura, bem como avaliar o efeito da sua aplicação sobre as propriedades físico-químicas, microbiológicas e sensoriais. Os objetivos específicos foram:

- Substituir a gordura em diferentes proporções pela BBV nas formulações de sorvete de coco;
- Determinar o efeito da adição da BBV sobre as propriedades físico-químicas do sorvete de coco;
- Realizar análise microbiológica para *Salmonella*, *Estafilococos coagulase* e *Enterobacteriaceae* no sorvete de coco;
- Efetuar teste de comparação múltipla para avaliar os atributos de qualidade do sorvete de coco com biomassa de banana verde em comparação ao padrão.

REVISÃO BIBLIOGRÁFICA

1. SORVETE

O sorvete é um complexo sistema alimentar composto por gordura emulsionada, proteína coloidal, bolhas e uma solução de lactose. Normalmente, o sorvete possui de 8 a 16% de gordura, o que influencia a textura, a manutenção da forma após o congelamento e a resistência ao derretimento. Isso ocorre devido à criação de uma rede de gordura que estabiliza as bolhas e as estruturas de espuma, aprimorando as propriedades de derretimento (Mostafavi, 2019). Segundo a Associação Europeia de Gelados, o sorvete é um produto alimentar que deve ser armazenado, transportado, vendido e consumido no estado congelado, contendo ingredientes e aditivos autorizados pelas normas vigentes, com estrutura e textura geradas por processo de congelamento (Euroglaces, 2013).

De acordo com a RDC n.713, de 1o de julho de 2022, o sorvete se enquadra na classe de gelados comestíveis que é definido como um produto congelado obtido a partir de uma emulsão de gorduras e proteínas ou uma mistura de água e açúcares, podendo incluir outros ingredientes, contanto que sua adição não altere as características essenciais do produto. Esta legislação estipula uma densidade aparente mínima de 475 gramas por litro de gelado comestível.

A ciência do sorvete consiste em compreender seus ingredientes, processamento, microestrutura e textura, sobretudo, a correlação existente entre eles. Por isso, se considera interdisciplinar por abranger a ciência de alimentos, ciência dos coloides, engenharia química, microscopia, ciência dos materiais e ciência do consumidor (Marshall; Goff; Hartel, 2003).

O sorvete é um alimento bastante versátil, por se apresentar em diversos sabores e cores correspondentes a texturas diferentes, como resultado da inserção de aditivos ou variações dos métodos de produção. Os sabores mais consumidos no mundo são baunilha, chocolate e morango. No entanto, nos últimos anos, têm sido implementadas novas estratégias de produção e marketing para encorajar os consumidores a experimentar novos sabores (FBI - Fortune Business Insights, 2022).

1.1.Tendências e oportunidades de mercado

O mercado global de gelados comestíveis está em constante evolução, impulsionado por mudanças nos comportamentos dos consumidores, inovações em produtos e novas tendências de consumo. No entanto, apesar do setor ter se adaptado rapidamente às demandas dos consumidores por produtos mais saudáveis e sustentáveis, os produtos ainda se encontram no final da lista dos mais consumidos (IDFA - International Dairy Foods Association, 2024).

De acordo com a Grand View Research (2023), uma tendência notável é a crescente demanda por produtos com rótulos limpos, sem aditivos artificiais, o que tem levado empresas nos Estados Unidos a lançar linhas de sobremesas congeladas não lácteas certificadas como veganas, orgânicas, 100% à base de suco de frutas e com baixo teor de açúcar, refletindo o aumento da demanda por opções de gelados *plant-based*.

O mercado de sorvetes no varejo brasileiro atingiu em 2023 o valor de 16,5 bilhões de reais, ou seja, cresceu 4,2% em relação ao ano anterior (Euromonitor Internacional, 2023). De acordo com a Mintel (2023), nos últimos três anos o segmento lançou 355 produtos novos, distribuídos em 155 sabores, para atender diferentes públicos.

Segundo a pesquisa de consumo da Mintel (2024), nove em cada dez consumidores do Reino Unido consumiram sorvete entre julho e outubro de 2023, e mais de 94% dos adultos estadunidenses compraram sorvete ou iogurte congelado em 2023. Além disso, o sorvete continua sendo amplamente apreciado como um alimento de conforto por muitos consumidores. Nos Estados Unidos, aproximadamente nove em cada dez pessoas que consomem sorvete afirmam que ele proporciona alegria quando precisam de um estímulo, ressaltando o papel consolidado do sorvete como um "alimento que traz conforto emocional" para os consumidores.

Este estudo acrescenta que desde a pandemia, houve uma mudança global em direção a uma alimentação mais consciente, assim os produtores de sorvete vêm-se por um lado inspirados na indústria de alimentos à base de plantas, adotando alternativas ao leite e focando na criação de sorvetes mais saudáveis, mas por outro no reforço a indulgência. Entretanto, embora haja essa tendência por parte dos consumidores, é improvável que o sorvete seja considerado verdadeiramente saudável. Portanto, o setor precisa encontrar um equilíbrio entre a indulgência e saudabilidade de seus produtos.

1.2.Legislação

Os gelados comestíveis, incluindo sorvetes, são consumidos mundialmente e diversos países e organizações estabelecem normas e padrões para assegurar a qualidade e a segurança desses produtos. As legislações geralmente abrangem aspectos como composição, rotulagem e aditivos permitidos. No Brasil, o Ministério da Saúde através da ANVISA, é a autoridade responsável pela regulamentação de gelados comestíveis, e o país também segue diretrizes internacionais estabelecidas por organizações como o Codex Alimentarius e a Federação Internacional de Laticínios (International Dairy Federation – IDF).

O Codex Alimentarius, criado pela FAO e pela OMS, estabelece padrões internacionais para gelados comestíveis, que visa proteger a saúde dos consumidores e garantir práticas equitativas no comércio. Por exemplo, o Codex Stan 243-2003 define as normas para sorvetes, incluindo limites para adição de açúcar, gordura e estabilizantes (FAO/WHO, 2003). Na União Europeia, a legislação sobre sorvetes inclui o Regulamento (CE) n.º 1333/2008 sobre aditivos alimentares, que estabelece listas de aditivos permitidos e suas condições de uso; a regulamentação da rotulagem de produtos alimentares, com detalhes sobre os valores nutricionais e diretrizes para a higiene e segurança alimentar, o Regulamento (CE) n.º 852/2004 (European Commission, 2004; 2008).

As gorduras totais ou saturadas podem ser classificadas em baixo, reduzido ou alto de acordo com a quantidade contida em uma porção de produto. Por exemplo, o alimento é considerado reduzido em gorduras totais ou saturadas se tiver uma redução mínima de 25% e o

alimento de referência não atender aos critérios para o atributo nutricional baixo em gorduras totais ou saturadas. Por outro lado, o sorvete enquadra-se na classificação de alimentos cuja energia é proveniente de carboidratos e gorduras, portanto, sua porção tem o tamanho de 60g ou 130ml (Anvisa, 2020).

1.3. Produção de sorvete

De acordo com Clarke (2012), a produção de sorvete envolve algumas etapas fundamentais:

- **Dosagem e mistura de ingredientes:** seleção e combinação de ingredientes líquidos e sólidos.
- **Pasteurização e homogeneização:** tratamento térmico da mistura para garantir segurança microbiológica e promover a dispersão uniforme dos componentes.
- **Maturação:** armazenamento refrigerado da base para favorecer a hidratação dos ingredientes com duração média de 8 a 12 horas.
- **Congelamento:** processo em que ocorre simultaneamente a formação de cristais de gelo, incorporação de ar (*overrun*) e estruturação da matriz do sorvete.
- **Envase e endurecimento:** transferência para recipientes e congelamento a temperaturas mais baixas ($-18\text{ }^{\circ}\text{C}$) por um período mínimo de 24h, conferindo consistência ao produto.

Figura 1 - Fluxograma de produção de sorvete.



Fonte: Elaborado pela autora (2024).

1.4. Ingredientes e formulações

Ao desenvolver um sorvete, deve-se levar em conta a função, o custo e a disponibilidade de cada ingrediente. Numa formulação, todos os ingredientes desempenham uma função importante nas características do produto, entretanto, as quantidades a serem adicionadas devem atender às legislações vigentes no país e equilibrar principalmente as proporções de gordura e açúcar (Marshall; Goff; Hartel, 2003).

A gordura é um dos principais ingredientes que determina a qualidade do sorvete, geralmente incorporada de 8 a 20%, desempenhando diversas funções, como garantir uma textura cremosa e suave, reduzir a velocidade de derretimento, intensificar o sabor e equilibrar a quantidade de espuma produzida. O creme, a gordura vegetal e a gordura de manteiga são as mais usadas para a produção do sorvete (Clarke, 2012).

Os açúcares exercem uma função importante para a aceitação global dos sorvetes, pois não apenas adicionam um gosto doce, mas também contribuem para a melhoria da textura, ao reduzirem o crescimento de cristais de gelo, que resulta em um produto com características mais macias, fáceis de serem servidas e mastigadas (Goff; Hartel, 2013).

Os estabilizantes são aditivos utilizados principalmente para manter a uniformidade e a textura dos alimentos, evitando a separação de ingredientes não miscíveis, como água e gordura, para diminuir o crescimento de cristais de gelo e manter a consistência desejada. Algumas substâncias comuns usadas como estabilizadores incluem goma guar, goma xantana, carragena e alginato de sódio (Clarke, 2012).

Os componentes sólidos do leite desnatado contribuem para a textura do sorvete, por meio do aumento da sua consistência. As proteínas presentes no leite possuem propriedades emulsificantes e têm a capacidade de criar uma estrutura de espuma, além de proporcionar estabilidade à interface do ar no sorvete. Da mesma forma, a lactose contribui com características semelhantes as dos açúcares e outros adoçantes, influenciando a qualidade geral do sorvete (Akbari; Eskandari; Davoudi, 2019).

No entanto, a indústria de sorvetes passou por mudanças relacionadas às matérias-primas utilizadas durante o processo de produção. A naturalização e incorporação de ingredientes saudáveis, que visam melhorar a composição do sorvete, representam as principais alterações (Pavlyuk et al., 2018). Portanto, é possível desenvolver sobremesas congeladas que sirvam como veículo de diversos nutrientes ou aditivos funcionais como antioxidantes e prebióticos, além de aplicar tecnologias que permitam reduzir ou eliminar a quantidade de alérgenos de origem animal adicionadas na sua produção (Aboulfazli; Baba; Misran, 2015).

O uso do leite de coco é uma das alternativas para redução de alérgenos de origem animal, extraído da fase final de maturação do fruto (Figura 2). É uma substância branca e leitosa obtida através do endosperma, rica em ácidos graxos de triglicerídeos de cadeia média, fornecendo energia rápida para o cérebro em comparação com outros tipos de leite com ácidos graxos de cadeia longa (Grumezescu; Holban, 2019). Também contém ácido láurico, que induz a apoptose (morte celular) em células cancerígenas da mama e do endométrio, estimulando o

sistema imunológico e mantendo a saúde vascular. Além disso, é rico em cálcio, fósforo, potássio, assim como vitaminas C, E e B6, lipídios e antioxidantes (Beegum et al., 2022).

Figura 2 - Diferentes estágios de maturação da variedade Malayan Green Dwarf (MGD) de coco.



Fonte: Lazim; Badruzaman (2015)

No entanto, a substituição da gordura do leite pela de coco requer muita atenção para que os efeitos positivos dos glóbulos de gordura na aparência cremosa, textura suave dos sorvetes sejam mantidos. Igualmente, a taxa de fusão do sorvete representa outro desafio por ser mais alta em gordura de coco em comparação com a do leite de vaca (Beegum *et al*, 2022). Assim, recomenda-se o uso de um tempo de maturação menor para as misturas que contêm gordura de coco (Clarke, 2012).

Por outro lado, as características qualitativas de sorvetes de coco podem ser facilmente alteradas com a aplicação de diferentes substitutos de gordura (Fuangpaiboon; Kijroongrojana, 2017). O principal desafio na utilização de leite de coco em gelados é alcançar a estabilidade do sistema coloidal (Aboulfazli; Baba; Misran, 2015). O leite de coco apresenta inicialmente as características de uma emulsão homogênea e estável, no entanto, ao longo do tempo, sofre uma separação de fases numa fração cremosa e numa fração aquosa, evidenciando a sua limitada estabilidade coloidal. Esta instabilidade representa um grande desafio na manutenção da integridade físico-química do leite de coco durante o armazenamento. Por isso, várias pesquisas são conduzidas para melhorar a sua estabilidade, entre as quais a homogeneização continua a ser a mais utilizada (Thirukumaran et al., 2023).

1.4.1. Gordura do coco

O leite de coco é uma fonte rica em aminoácidos essenciais e lipídios, contendo aproximadamente 35,2% de gordura e 3,8% de proteínas na sua forma pura (Wu et al., 2023). Em um estudo de Chen *et al.*, (2024), sobre o impacto do teor de gordura na estabilidade do leite de coco, foi observado, por um lado, que as lactonas presentes no óleo de coco, que conferem ao leite de coco um sabor cremoso e frutado, influenciando diretamente seu sabor e

estabilidade. Entretanto, o aumento do teor de gordura resulta em gotas de leite de coco maiores e mais viscosas, cuja estabilização é impulsionada por interações hidrofóbicas.

Além disso, leites de coco com 10% de gordura demonstraram excelente estabilidade de armazenamento, estabilidade à oxidação da gordura e resistência ao congelamento e descongelamento. O leite de coco com 10% de gordura mostrou uma maior interação com enzimas pancreáticas e uma viscosidade adequada, indicando propriedades digestivas favoráveis (Chen *et al.*, 2024).

1.4.2. Gorduras tradicionais em formulações de sorvete

A principal fonte de gordura para preparação de sorvete é o leite, especificamente o creme de leite fresco que melhor confere sabor, por isso, é fundamental que ele seja de qualidade desejável e livre de rancidez e oxidação lipídica. O leite concentrado ou em pó (integral ou desnatado) com maiores concentrações de sólidos do leite não-gordurosos e o leite (integral ou desnatado) que fornece água a mistura são frequentemente usados na produção de sorvetes, em combinação com o creme de leite. No entanto, o creme de leite é considerado a fonte de gordura mais cara em comparação as demais, por isso, a indústria de sorvete começou a considerar o uso de outras opções de gordura (Goff; Hartel, 2013).

Na escolha da fonte de gordura, alguns fatores considerados são a rapidez com que a gordura cristaliza, que afeta parcialmente o tempo de maturação; a configuração cristalina da gordura; o perfil de derretimento da gordura em diversas temperaturas, especialmente em ambientes de refrigeração e congelamento; a presença de triglicerídeos com alto ponto de fusão, que pode resultar em uma sensação cerosa e oleosa na boca; e, por fim, o sabor e a pureza do óleo (Tran; Rousseau, 2016; Moorthy, 2018).

Por exemplo, a gordura de coco geralmente cristaliza mais rapidamente que a gordura do leite, pelo fato da gordura de coco ser composta predominantemente por ácidos graxos de cadeia média, que tendem a formar cristais mais rapidamente do que os ácidos graxos de cadeia longa presentes na gordura do leite. Consequentemente, o tempo de maturação é mais prolongado para formulações com gordura do leite, permitindo uma estrutura mais estável e homogênea no produto em comparação as com gordura de coco onde a cristalização rápida pode reduzir significativamente o tempo de maturação (Chaleepa, Szepes, Ulrich; 2010; Clarke, 2012; Sonwai, Podchong, Rousseau; 2016).

O óleo de coco é rico em ácidos graxos saturados, com aproximadamente 90% de sua composição. Embora seja eficaz na produção de um sorvete, ele apresenta a desvantagem nutricional de possuir um alto teor de gordura saturada. Por outro lado, o óleo de palma possui uma menor quantidade de gordura saturada, cerca de 50%, mas por ser parcialmente sólido a 35°C (temperatura próxima a da boca), o sorvete feito com óleo de palma pode resultar na presença de gordura sólida na boca durante o consumo, o que pode causar uma sensação desagradável de cera (Clarke, 2012; Suryani et al., 2020).

1.4.3. Questões de saúde associadas às gorduras tradicionais

A ingestão excessiva de gorduras está diretamente associada ao surgimento de doenças crônicas não transmissíveis, como a obesidade e diabetes tipo 2. Essas condições de saúde têm impactos significativos e ressaltam a importância de uma abordagem equilibrada e consciente em relação à alimentação (Balivo; D'errico; Genovese, 2024). Ademais, a presença de um teor relativamente alto de ácidos graxos saturados na gordura do leite está associada a efeitos negativos à saúde, que podem aumentar o risco de doenças cardiovasculares devido a elevação do nível do colesterol e da lipoproteína de baixa densidade (FAO, 2010).

A *American Dietetic Association* (2005) definiu diversos termos, como produtos láteos com teor reduzido de gordura, *light*, com baixo teor de gordura e sem de gordura. Atualmente, é aconselhado que o consumo de gordura seja limitado a menos de 30% das calorias totais, sendo que as gorduras saturadas devem compor menos de 10% da ingestão energética total. Além disso, a *American Heart Association* recomenda que pessoas com níveis elevados de colesterol de lipoproteína de baixa densidade ou com doenças cardiovasculares restrinjam as gorduras saturadas a menos de 7% das calorias totais (Abbas et al., 2024).

O desenvolvimento de produtos alternativos de alta qualidade e com baixo teor de gordura tem exigido extensas pesquisas, buscando uma combinação de ingredientes, incluindo substitutos de gordura, capaz de replicar as características de textura e sabor proporcionadas pela gordura no sorvete (Cardoso et al., 2023).

1.4.4. Substitutos de gorduras em sorvetes

Os substitutos de gordura podem ser derivados de carboidratos, proteínas ou lipídios, e seu principal objetivo é reduzir o valor calórico do produto, enquanto mantém características de qualidade similares das gorduras tradicionais. Isso pode ser alcançado diminuindo a quantidade necessária na formulação ou reduzindo as calorias por unidade de peso do ingrediente utilizado (Saeed et al., 2023). Adicionalmente, esses substitutos de gordura desempenham outras funções, tais como melhorar a textura, servir como estabilizadores, emulsificantes, agentes de formação de gel e espessantes (Gao et al., 2024).

Existem vários tipos de substitutos de gordura (Tabela 1) utilizados para amenizar os efeitos negativos nas características de textura e sensoriais dos produtos, advindos da redução ou remoção da gordura. Eles podem ser adicionados em sorvetes com baixo teor de gordura de forma individual ou por meio de combinações, uns com outros, para o alcance de qualidade satisfatória (Akbari; Eskandari; Davoudi, 2019).

Em formulações de sorvetes com reduzido teor de gordura, diversos atributos de qualidade, incluindo a dureza, são impactados. A dureza se relaciona inversamente à quantidade de gordura presente, significa que sorvetes mais macios costumam conter uma maior quantidade de gordura em sua composição, enquanto os mais rígidos têm menos gordura. Essa variação ocorre devido ao aumento na formação de cristais de gelo quando a gordura é

diminuída, o que diferencia o produto das formulações tradicionais (Akbari; Eskandari; Davoudi, 2019).

Normalmente, cristais de gelo com tamanhos maiores que 50µm conferem uma textura arenosa, já os menores com cerca de 10 a 20 µm resultam em texturas mais apreciadas pelos consumidores. Além disso, o tamanho do cristal de gelo influencia a vida útil do sorvete devido ao processo de recristalização e oscilações de temperatura do freezer que promovem continuamente o aumento do seu tamanho (Marshall; Goff; Hartel, 2003; Eisner; Wildmoser; Windhab, 2005).

Tabela 1 - Tipos de substitutos de gordura mais comuns em sorvetes.

Gordura Substituta	Referências
Maltodextrina	Güzeler, Kaçar e Say (2011); Karaca <i>et al.</i> (2009).
Polidextrose	Li <i>et al.</i> (1997); Güzeler, Kaçar e Say (2011).
Proteínas do leite	Akalın, Karagözlü e Ünal. (2008); Ohmes, Marshall e Heymann (1998); Yilsay, Yilmaze e Bayizit (2006); Karaca <i>et al.</i> (2009); Mostafavi, Tehrani e Mohebbi (2017).
Proteínas de soja	Liu <i>et al.</i> (2018)
Fructo-oligossacarídeos	Akalın, Karagözlü e Ünal. (2008); Akin, Akin e Kirmaci (2007); Akalin e Erisir (2008); Ismail, Al-Saleh e Metwalli (2013); Soukoulis, Lebesi e Tzia (2009); Karaca <i>et al.</i> (2009)
Gomas vegetais	Javidi e Razavi (2018)
Cereais e fibras alimentares à base de frutos	Soukoulis, Lebesi e Tzia (2009)
Amido	Aime <i>et al.</i> (2001); Surapat e Rugthavon (2003); Sharma, Singh e Yadav (2017)

Fonte: Adaptado de Akbari, Eskandari e Davoudi (2019).

2. BIOMASSA DE BANANA VERDE E SEUS BENEFÍCIOS NUTRICIONAIS

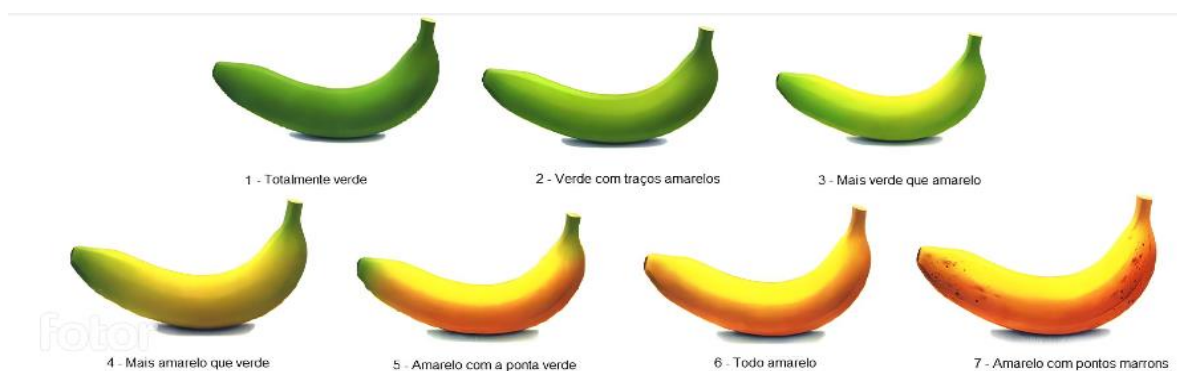
A banana (*Musa sp.*) é um fruto produzido mundialmente, encontrado em mais de 107 países que totalizam cerca de 88 milhões de toneladas de produção anual para consumo (FAO, 2020; 2023). Em 2021, o Brasil produziu aproximadamente 7 milhões de toneladas, em uma extensão de 453.273 hectares (EMBRAPA, 2022).

A América Latina e Caraíbas representam a principal região exportadora no mundo, no entanto, em 2022, teve seus níveis reduzidos a 5,7%, equivalente a 14,5 milhões de toneladas - cerca de 900 000 toneladas abaixo do seu nível de 2021. O Equador é o maior exportador de banana a nível mundial, no entanto, sofreu também declínio de 12,4% nas exportações em 2022, totalizando uma queda de aproximadamente 5,8 milhões de toneladas (FAO, 2023).

De acordo com Jiang *et al.* (2015), a banana é mais consumida na forma madura e cerca de um terço da sua produção é descartada no período pós-colheita, visto que se trata de um fruto climatérico, muito suscetível a danos mecânicos e perecibilidade durante a maturação, dificultando o seu armazenamento e transporte. Nesse contexto, a adoção de mecanismos para reduzir as perdas da produção através do processamento da banana verde foram avaliados e demonstraram ser bastante promissores (Anyasi; Jideani; Mchau, 2013; Jiang *et al.*, 2015; Zandonadi *et al.*, 2012).

A biomassa de banana verde é um produto derivado do processamento de bananas verdes. É obtida por meio do cozimento da banana em seus estágios iniciais de maturação, geralmente 1 e 2, conforme classificação descrita na escala de maturação (Figura 3), proposta em 1950, ou seja, é transformada em uma pasta ou polpa (Figura 4) que pode ser utilizada em várias aplicações alimentícias e industriais como pães, bolos, massas, maionese, sorvetes, entre outros (Auriema *et al.*, 2022).

Figura 3 - Escala de maturação da banana.



Fonte: Google imagens (2024).

Figura 4 - Biomassa de banana verde



Fonte: Google imagens (2023).

A biomassa de banana verde é conhecida por sua elevada quantidade de amido, uma fibra funcional com alta potencialidade no controle glicêmico e lipídico no organismo humano, baixos teores açúcares e compostos aromáticos. A sua aplicação em produtos alimentícios é bastante versátil, uma vez que seu uso não provoca alterações perceptíveis no sabor ou aroma dos alimentos, podendo substituir a gordura e enriquecer diversos produtos, como pães, massas em geral, sorvetes e alimentos que contenham amido em sua composição (Tan; Beltranena; Zijlstra, 2021).

O amido presente na banana verde contém baixo teor de amilase, tem resistência ao aquecimento e inchaço e, baixa retrogradação, propriedades que lhe conferem boas possibilidades de aplicação na indústria como gelificantes, espessante ou estabilizadores. No caso de produtos lácteos, a biomassa de banana verde pode ser aplicada em vários tipos de sobremesas por ser inodora e com boa solubilidade (Padam *et al.*, 2014; Khoozani; Birch; Bekhit, 2019).

No Brasil, são escassos os estudos realizados com aplicação da biomassa de banana verde em sorvetes (Tabela 2), alguns deles são com sorvete sabor de maracujá (Aragão *et al.*, 2018) e sorvete de chocolate (Wrobel; Teixeira, 2017). Acosta-Coell, Parodi-Redhead e Medina-Pizzali (2021) ressaltam que uma das principais vantagens do uso da BBV como um ingrediente é que sua matéria-prima é de fácil acesso e está disponível durante todo ano.

Recentemente, Cardoso *et al.* (2023) incorporaram a biomassa de banana verde em sorvete de baunilha com objetivo de substituir parcialmente o creme de leite, onde se verificou que a BBV foi eficaz para reduzir o teor de gordura no sorvete caseiro. No entanto, recomendam mais estudos para otimizar a concentração de BBV que permita a substituição máxima de gordura e aumento do conteúdo de amido resistente, sem prejudicar as características tecnológicas e sensoriais do produto.

Tabela 2 - Impactos da utilização da biomassa de banana verde como ingrediente em sorvetes e respectivas análises físico-químicas e sensoriais.

	Sorvete caseiro de baunilha	Sorvete de chocolate	Sorvete de maracujá
Objetivo	Elaborar e caracterizar formulações de sorvete caseiro feitas a partir da substituição parcial de gordura láctea por BBV	Elaborar e caracterizar sorvete de chocolate com adição de BBV	Elaborar e caracterizar sorvete utilizando a BBV e a sucralose como substitutos de gordura e açúcar (sacarose), respectivamente.
Tratamento	Quantidade BBV: -F1: 0g -F2: 350g -F3: 400g	Quantidade BBV: -F1: 0% -F2: 2.6% -F3: 12.5% -F4: 21.9%	Quantidade BBV e sucralose: -F1: 0%, 0% -F2: 5%, 0% -F3: 5%, 17,5%
Propriedades físico-químicas	Maior acidez titulável com adição de BBV; Fusão: redução das taxas de colapso em BBV baixas.	Maior acidez titulável com adição de BBV; Teor de gordura maior nas formulações com biomassa; Maior overrun com adição de BBV.	F3 com maior teor de água e pH; Maior °Brix para F1 (controle). Maior teor de lipídios para controle (F1) em relação às F2 e F3 (p<0,05).
Análise sensorial	Preferência: formulação tradicional; Cor: mais marrom com o aumento da [BBV];	Cor, sabor, textura, aparência e aceitação global sem diferenças significativas.	N/A
Referências	Cardoso et al., 2023	Wrobel e Teixeira, (2017)	Aragão et al, 2018

Fonte: Elaborado pela autora (2024).

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CAPÍTULO I

MIMÉTICOS DE GORDURA À BASE DE AMIDO EM SORVETES: TENDÊNCIAS BIBLIOMÉTRICAS E APLICAÇÕES TECNOFUNCIONAIS

STARCH-BASED FAT MIMETICS IN ICE CREAM: BIBLIOMETRIC TRENDS AND TECHNO-FUNCTIONAL APPLICATIONS

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ABSTRACT

Starch-based fat substitutes provide an effective alternative for reducing lipid content in ice cream while preserving its desirable sensory and technological properties. Additionally, they help mitigate the risks associated with excessive fat consumption, such as obesity, type 2 diabetes, heart disease, and high blood pressure. This review explores recent advances in the use of native and modified starches, highlighting their physicochemical properties, mechanisms of action, and impact on ice cream formulations. Chemical, physical, and enzymatic modifications, along with nanotechnology, are key approaches for enhancing the functionality of native starches in intricate food structures. Findings indicate that resistant starches and starch nanocrystals more effectively replicate the creaminess and stability of traditional fats while providing functional benefits such as reduced glycemic impact and increased dietary fiber. However, challenges related to cost, scalability, and sensory balance must be addressed to facilitate their industrial application. Recent studies reinforce the potential of these substitutes in the formulation of nutritionally improved and sustainable ice creams.

Keywords: Fat mimetics, Starch, Ice cream, Food industry.

1. INTRODUCTION

In human nutrition, fat is a necessary component, as it provides energy and facilitates fat-soluble vitamin absorption (Abbas et al., 2024). In addition, it contributes significantly to the sensory quality of foods. Fat contributes to flavor by acting as a carrier of aromatic compounds and improves texture by providing smoothness and desirable melting properties in ice cream (López-Martínez, Moreno-Fernández, Miguel, 2021; Cardoso et al., 2023).

Despite its essential functions, excessive fat consumption is linked to a significant chance of developing chronic illnesses, such as heart disease, type 2 diabetes, hypertension, obesity, and certain types of cancer (Hooper et al., 2020). Therefore, the World Health Organization (WHO) recommends that 10% or less of total energy consumption should come from saturated fat, while total fat intake should account for at least 30% of total energy (WHO, 2023).

Reducing or removing fat from food is often necessary to align with health guidelines. However, this process can negatively impact essential characteristics such as texture and flavor. To address this challenge, the food industry has advanced by developing fat substitutes designed to retain the sensory and techno-functional properties of products (Shaheen et al., 2023). Among these substitutes, fat mimetics commonly derived from proteins or carbohydrates are highly used because they replicate the physicochemical and sensory properties of triglycerides, although they cannot replace them directly on a gram-per-gram basis (Solanke et al., 2016). Additionally, starch-based substitutes, sourced from plants like corn, wheat, potato, and rice, represent a promising alternative (Kunle, 2019).

In ice cream matrices, a complex multi-phase food matrix comprising emulsion, gel, suspension, and foam, fat plays a fundamental role. It constitutes between 10% and 16% of the formulation and is essential for shape retention, melt resistance, and smoothness in the final product. Beyond its influence on texture and mouthfeel, fat also facilitates the release of aromatic compounds, making it indispensable for the sensory experience (Akbari, Eskandari, Davoudi, 2019; Marimon-Valverde et al., 2024).

Given this, to meet the growing demand for healthier foods, the industry has explored alternatives to reduce fat content without compromising sensory quality. While fat substitutes have been extensively studied, the application of starches as fat mimetics in ice cream remains an underexplored area. This field requires solutions that not only reduce lipid content but also preserve essential characteristics such as creaminess and structural stability. Starches emerge as a promising alternative, as they can replicate the physicochemical properties of lipids while acting as stabilizing and structuring agents. This makes them viable alternatives for the formulation of low-fat ice creams without compromising consumer acceptance.

Meanwhile, to ensure the effectiveness of this application, it is crucial to comprehend the effects of starch-based substitutes on the physicochemical, functional, and sensory properties of ice cream. Therefore, we believe that an updated review on this subject would offer valuable insights into recent advances aimed at overcoming the limitations of native starch from various sources, including conventional ones such as corn, wheat, potato, and cassava, as well as unconventional sources like green banana, nuts and by-products, some of which are also rich in resistant starch and dietary fiber, through the application of different modification techniques, including sustainable methods.

Furthermore, we aim to explore the functionality of starch-based fat mimetics within the ice cream matrix, emphasizing their effects on texture, rheology, creaminess, melting behavior, and overall functional and sensory properties. To support the relevance and growing interest in this field, as well as identify the publication trends, key contributors, understand the current state of the art and highlight emerging concerns, a bibliometric analysis was conducted using Bibliometrix R-package.

2. METHODOLOGY

2.1. Data acquisition

A bibliographic study was carried out using the Scopus® and Web of Science® (WoS) databases. This study aligns with recent research highlighting the benefits of integrating these databases for bibliometric analyses, particularly in studies on recent advances in the use of native and modified starches, emphasizing their physicochemical properties, mechanisms of action, and impact on ice cream formulations (Robledo and Zuluaga, 2023).

The search strategy employed Boolean operators to ensure the inclusion of the most relevant articles, using keywords in English such as "starch AND ice cream." The search covered studies published between 2001 and 2025, and data collection was conducted on February 24, 2025. The search terms included "starch," "fat mimetics," "resistant starch," "ice cream," and "fat replacement in ice cream." Scopus® and Web of Science® databases returned 124 and 139 documents, respectively. After merging the datasets, duplicate records were removed, resulting in 86 unique articles (Figure 1). These articles were screened by reviewing their titles and abstracts to assess their relevance to the study.

In addition to basic bibliographic details such as author(s), title, publication year, source title, volume, issue, page numbers, and citation count, the collected metadata also comprised information like author affiliations, series identifiers (e.g., ISSN), DOI, publisher, editor(s), original language of the document, mailing address, abbreviated journal title, abstract, author-provided keywords, indexing keywords, and funding information, including funding numbers, acronyms, sponsors, and funding descriptions. All metadata were exported and stored in CSV format to support subsequent analyses.

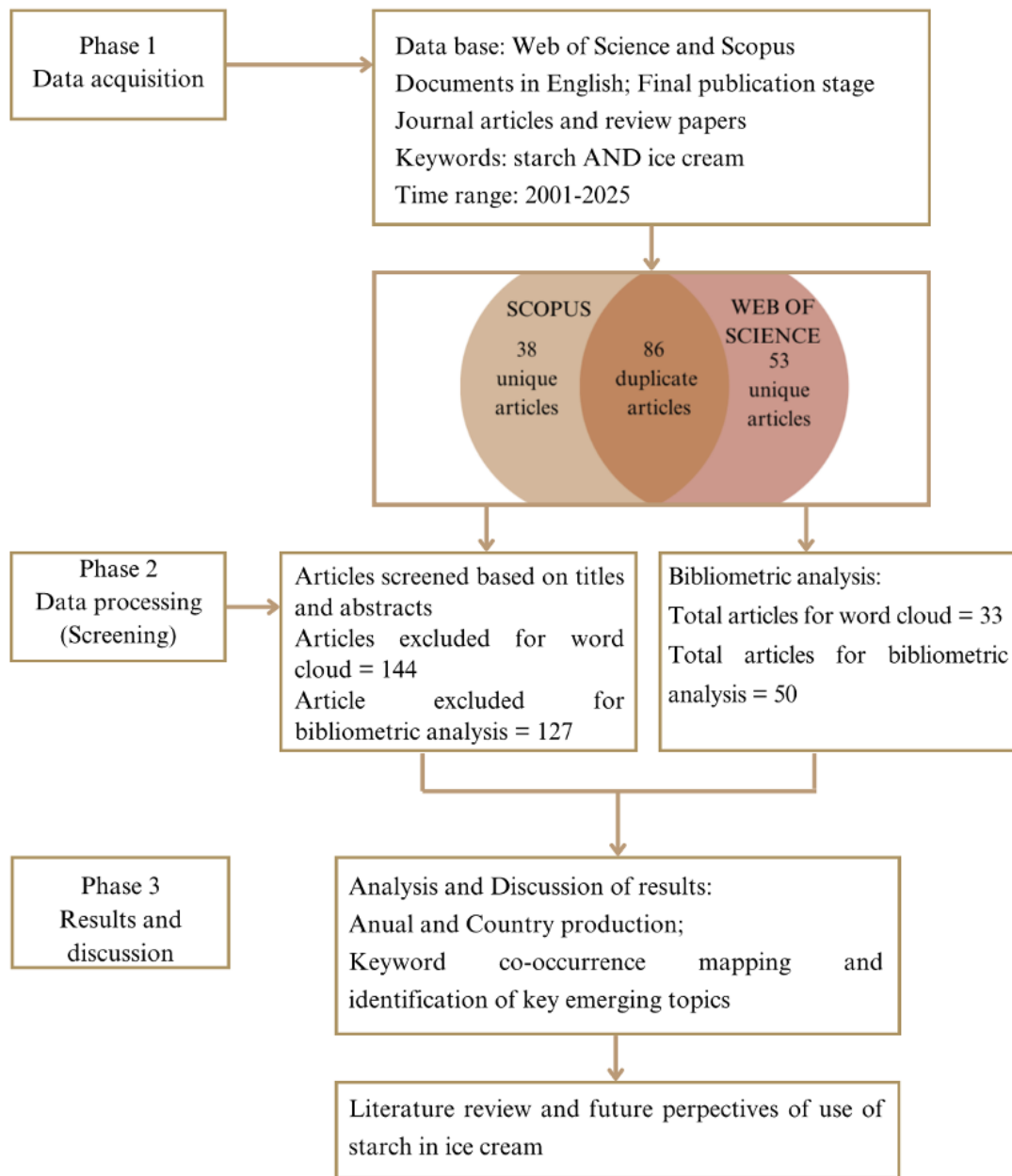


Figure 1. Identification and screening criteria of articles from a search of the WoS and Scopus database (with the most recent data searched on February 24, 2025).

2.2.Data analysis

Scientific mapping and descriptive statistical analysis were conducted using the Bibliometrix R package integrated into R 3.5.1 (R Core Team, 2003). The analysis encompassed the identification of key research topics, countries with the highest publication density, the most influential studies, leading authors, popular journals, institutions with the highest number of cited scientific articles, and the keyword co-occurrence network, annual trends in publication and citation counts.

2.3.Results and discussion of bibliometric

A global map illustrating the countries that have contributed to research on starch-based fat mimetics and their application in ice cream is presented in Figure 2. The map uses different shades of blue to represent scientific productivity levels, where darker shades indicate higher research output, and gray signifies the absence of published studies on the topic. Currently, 10 countries have conducted academic research in this field, with Iran (darker shades blues) leading in the number of scientific publications (n = 17), followed by Brazil (n = 9), China (n = 9), and India (n = 9).

The bibliometric analysis revealed significant fluctuations in the number of publications related to starch and ice cream over the years (Figure 2). The first relevant study was published in 2001, followed by a gap in publications from 2003 to 2006. A modest resurgence was observed in 2007, suggesting a renewed but short-lived interest in this topic. From 2008 to 2016, the number of publications remained relatively low.

However, a notable increase occurred in 2017, suggesting a greater awareness and acknowledgment of the potential applications of starch in frozen dessert formulations. Although there was a slight decline in the subsequent years, interest in this topic regained momentum in 2023 and continued into 2024. As data collection for 2025 was conducted early in the year, it is not yet possible to determine the complete trend for this period. Nevertheless, the recent upsurge in publication activity highlights a renewed scientific interest in starch-based ingredients in ice cream, likely driven by the need for clean-label products and healthier fat substitutes.

Figure 3 presents a word cloud of the most used key keywords. This analysis provides a clearer understanding of the key keywords found in scientific literature related to starch-based fat substitutes and their use in ice cream. The most frequently appearing terms in studies on this subject include "starch," "ice cream," "sensory properties," "rheological properties," "physicochemical properties," "milk fat," "inulin," and "functional properties."

These terms highlight the dual motivation behind this research: improving the technological performance of ice cream while also meeting consumer demands for healthier, low-fat, natural and functional ingredient-based products. The frequency of appearance of the term sensory properties suggests that a significant portion of the research is dedicated to evaluating the impact of starch-based fat mimetics on sensory attributes such as texture, flavor, and overall acceptability, which are fundamental parameters for consumer satisfaction and product success in the market.

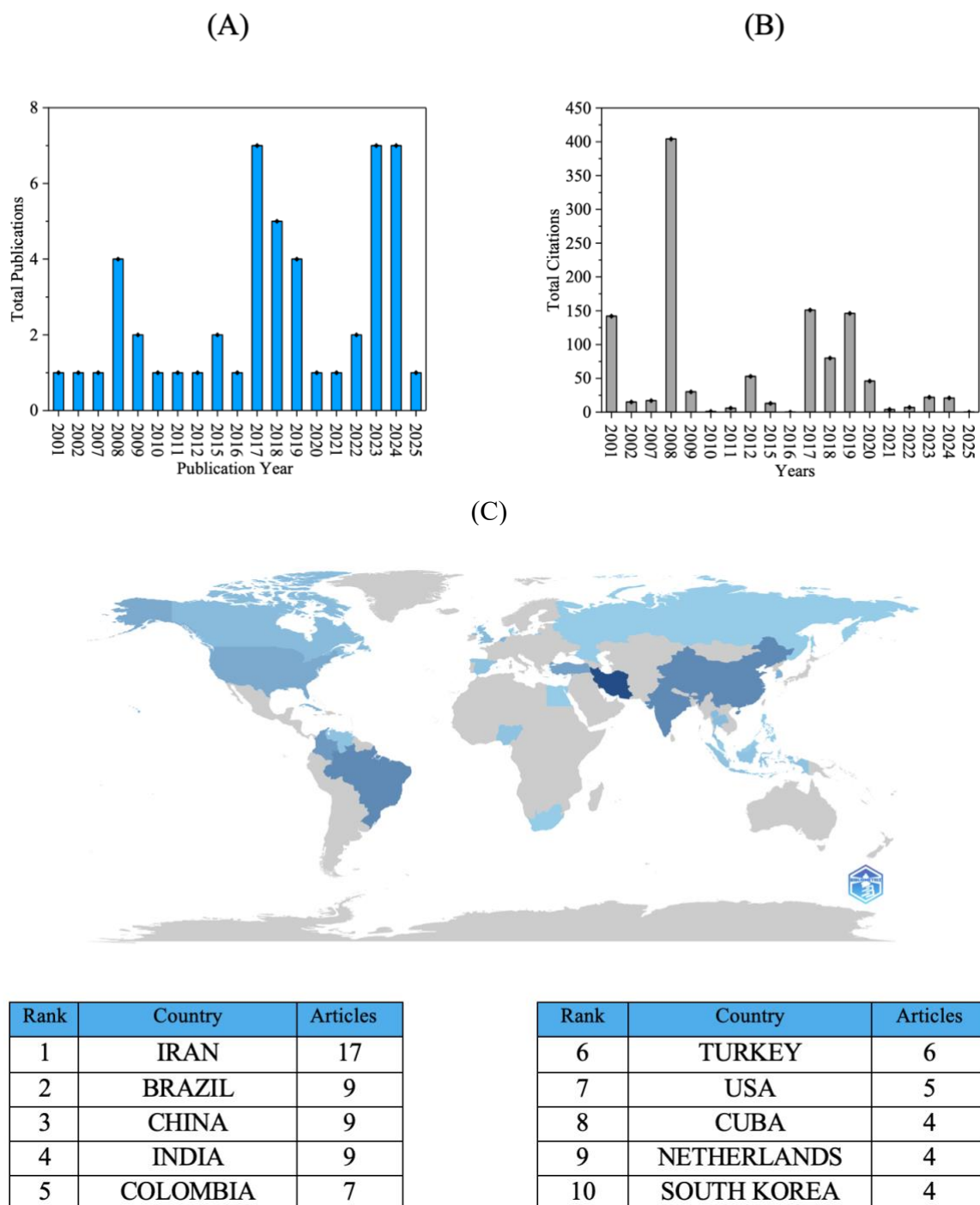


Figure 2. Trends in the publication of scientific articles on advances in starch-based fat mimetics and their application in ice cream: number of publications per year (A) and number of citations per year (B). Geographic distribution of publications (C). Data sourced from WoS and Scopus databases for the period 2001–2025. The analysis was conducted using Bibliometrix, with the most recent search performed on February 24, 2025.



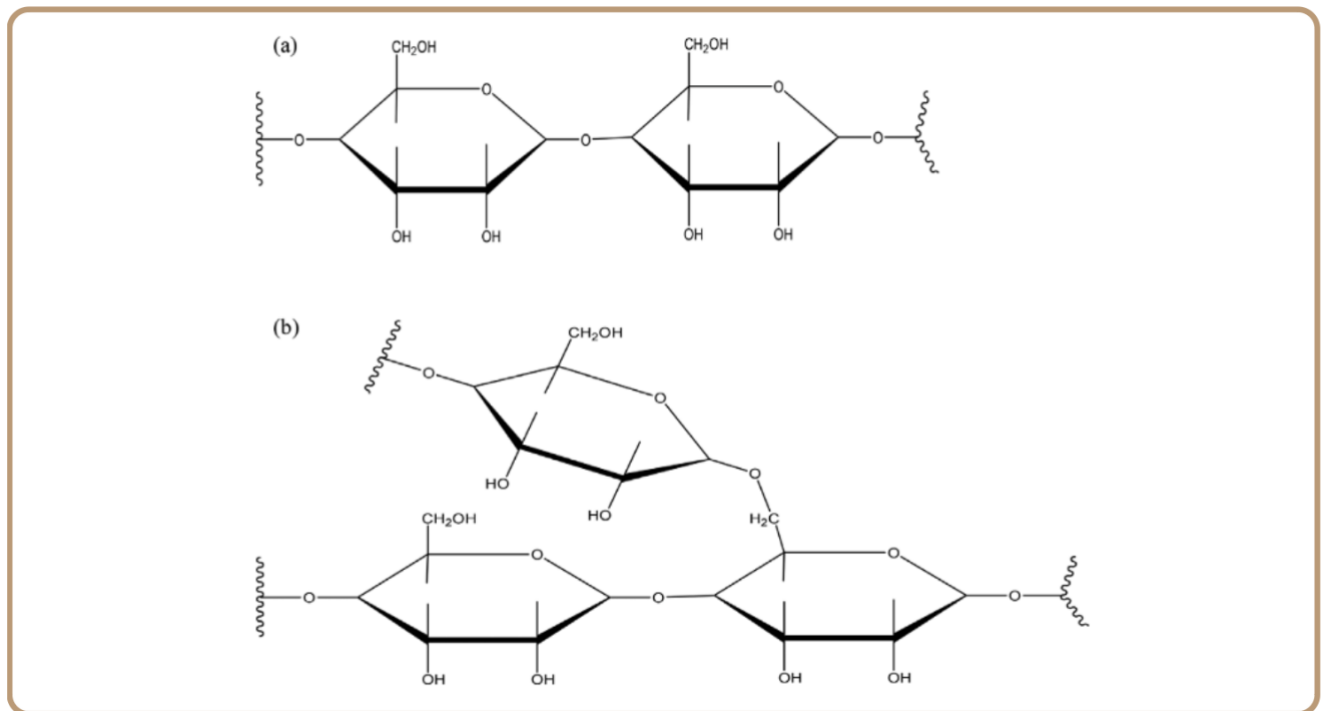
Figure 3. Network visualization of author keywords using data from WoS and Scopus databases covering the publication period from 2001 to 2025. (The result was conducted by Bibliometrix, with the most recent data searched on February 24, 2025).

3. PROPERTIES AND LIMITATIONS OF NATIVE STARCH FOR REPLACING FAT IN ICE CREAM

3.1. Structure and composition of native starch

Starch is a sustainable, non-toxic, non-allergenic, cost-effective, and abundant polymer from plants. It is not only an essential component of the human diet but also widely used in various industrial applications (Zhu, 2017; Zhao et al., 2018). This polymer consists of two main polysaccharides: amylose and amylopectin. Amylose consists of linear glucose chains with few branches and α (1 $\rightarrow$ 4) linkage, whereas amylopectin is highly branched with both α (1 $\rightarrow$ 4) and α (1 $\rightarrow$ 6) linkages, containing short chains with frequent branching points (Figure 4a) (Sharanagat et al., 2023).

(4A)



(4B)

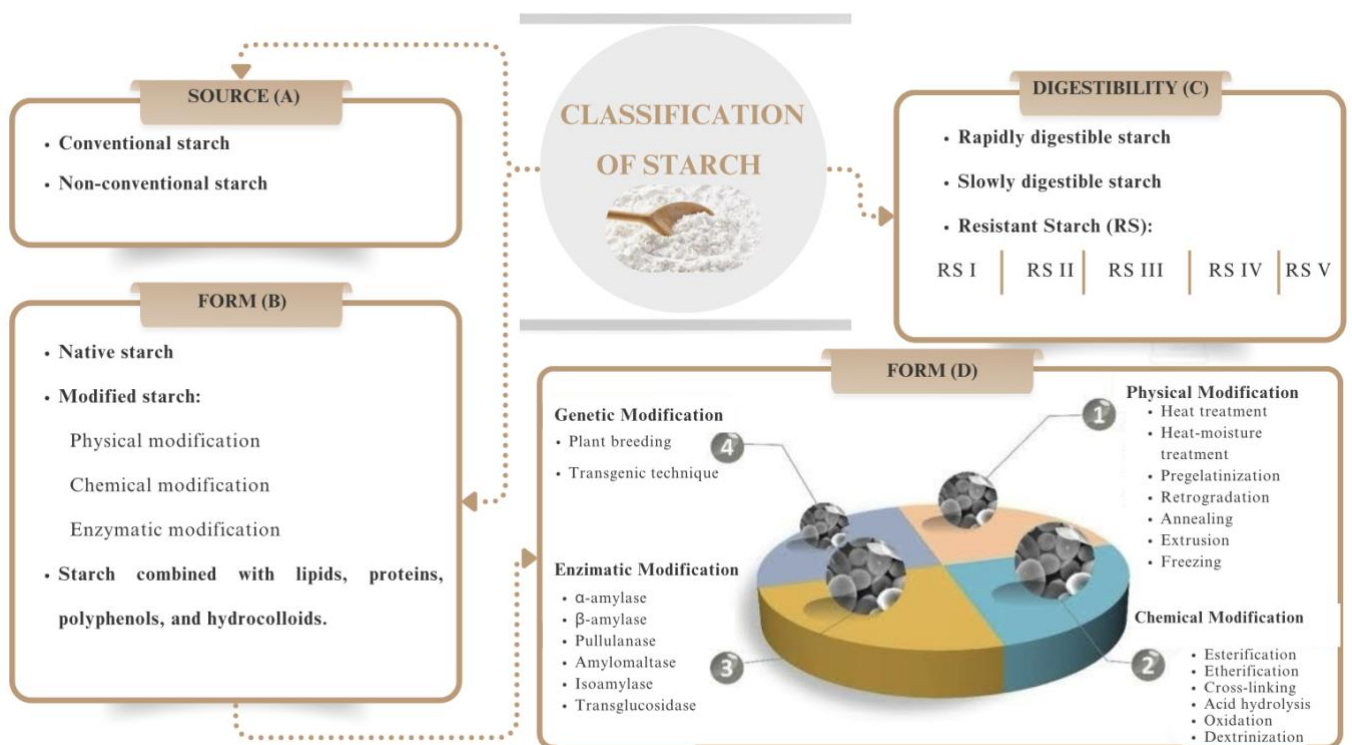


Figure 4. (A) Representative chemical structures of D-glucose units showing an $\alpha(1\rightarrow4)$ linkage in amylose **(a)** and both $\alpha(1\rightarrow4)$ and $(1\rightarrow6)$ linkages in amylopectin **(b)** Source: (Builders; Arhewoh, 2016). **(B)** Classification of starch based on source, digestibility, and form (A, B, C). Adapted from: (Yashini et al., 2024); Description of different starch modification techniques (D). Adapted from Singh et al., (2023).

Furthermore, the amylose and amylopectin found in the starch granule are organized into water-soluble lamellae and a semicrystalline structure. In starches extracted from plants, amylose typically represents 20–30%, while amylopectin accounts for 70–80%, a proportion that is essential in determining their physicochemical properties (Yazid et al., 2018). The interaction between amylose and amylopectin influences functional characteristics such as shear resistance, gel stability, solubility, viscosity and the processes of gelatinization and retrogradation (Klaochanpong et al., 2015). Additionally, starch varies among different plant species, presenting variations in morphological, thermal, rheological, functional, and physicochemical characteristics (Chavan et al., 2021).

Figure 4b presents the classification of starch according to its source, form, and digestibility. Generally, conventional starch sources include wheat, corn, potato, and cassava, although some fruits also provide significant amounts of starch with distinct morphology and properties (Chen et al., 2020). Crops such as sweet potato, yam, and arrowroot have high total and resistant starch content, making them significant sources of dietary fiber as well (Yazid et al., 2018). Moreover, fruits such as plantain, mango, and avocado, as well as legumes, nuts, and jackfruit seeds, are considered non-conventional starch sources, although their commercialization remains limited (Kringel et al., 2020; Yashini et al., 2024). Other starch-rich foods include millet and sorghum flours, which have potential applications as fat replacers in food formulations (Lin et al., 2024).

Regarding digestibility (Figure 4b), they are typically separated into slowly digestible starch (SDS), rapidly digestible starch (RDS), and resistant starch (RS). RDS are hydrolyzed rapidly by digesting enzymes, leading to a sharp postprandial elevation of insulin and blood glucose levels. This behavior is attributed to their high amylopectin content, a complex, crystalline polymer that is highly branched and facilitates enzymatic access. On the other hand, glucose is released more gradually and continuously from SDS. The main cause of this slower digestion is the increased amount of amylose, a linear glucose polymer with 500-20 000 units. The compact and less branched structure of amylose contributes to decreasing glycaemic effect and digestibility (Yashini et al., 2024).

Resistant starch (RS) is the indigestible portion of starch that is not hydrolysed by enzymes in the small intestine, particularly by α -amylase and reaches the colon intact. The local microbiota ferments it there, generating short-chain fatty acids that promote intestinal health. Due to its physiological behavior, RS is acknowledged as a form of dietary fiber and is considered a functional component in healthy foods (Bojarczuk et al., 2022 ; Yashini et al., 2024). Fruits and their residues have shown potential as sources of non-conventional starch (Kringel et al., 2020).

Cardoso and collaborators (2023) demonstrated a gradual rise in dietary fiber and resistant starch content in formulations with green banana biomass. Considering that dietary fiber and resistant starch have comparable physiological benefits, formulations with 12.5% and 21.9% fat replacement were deemed adequate sources of this starch. According to Brazilian regulations and European Parliament and Council, a food product may be classified as a “source of fiber” or “contains fiber” if it has a minimum of 3 grammes of fiber per 100 grams of product (EC, 2011; Cardoso et al., 2023).

Additionally, RS is divided into five categories based on its digestibility mechanisms. RS I refers to starch physically inaccessible to enzymes, found in whole or coarsely ground grains, seeds, and legumes. RS II includes raw starch granules with a compact crystalline

structure, such as those in green bananas and raw potatoes. RS III, or retrograded starch, forms when gelatinized starch is cooled, increasing its resistance to digestion, as seen in cooled pasta, rice, or potatoes. RS IV comprises chemically modified starches designed to resist enzymatic breakdown, commonly used in processed foods. RS V consists of amylose-lipid complexes that are water-insoluble and enzyme-resistant, occurring naturally in some baked goods or synthetically in products like resistant maltodextrins (Raigond; Ezekiel; Raigond, 2015; Bojarczuk et al., 2022; Yashini et al., 2024).

3.2.Functional properties of native starch

Starch has important functional properties in improving food texture, acting as a thickener, bulking agent, adhesive, and gelling agent (Chavan et al., 2021). Additionally, when dispersed in food systems, starch granules can provide sensory characteristics similar to those of fat globules (Peng and Yao, 2017).

The functionality of starch depends on its granular structure and the proportion between amylose and amylopectin. Starches with smaller granules, resembling fat emulsions, can be added to food compositions as fat substitutes (Kunle, 2019). The individual dispersion of starch granules mimics the droplets in emulsions (Figure 5), influencing texture and sensory perception (Peng and Yao, 2017). Small starch particles extracted from wheat and amaranth have been tested in frozen desserts as fat substitutes. Up to 50% of the fat was successfully replaced with only 2% starch, without compromising sensory acceptance (Malinski et al., 2003). This replacement is due to the three dimensions system created by starch that simulates the creaminess provided by lipids.

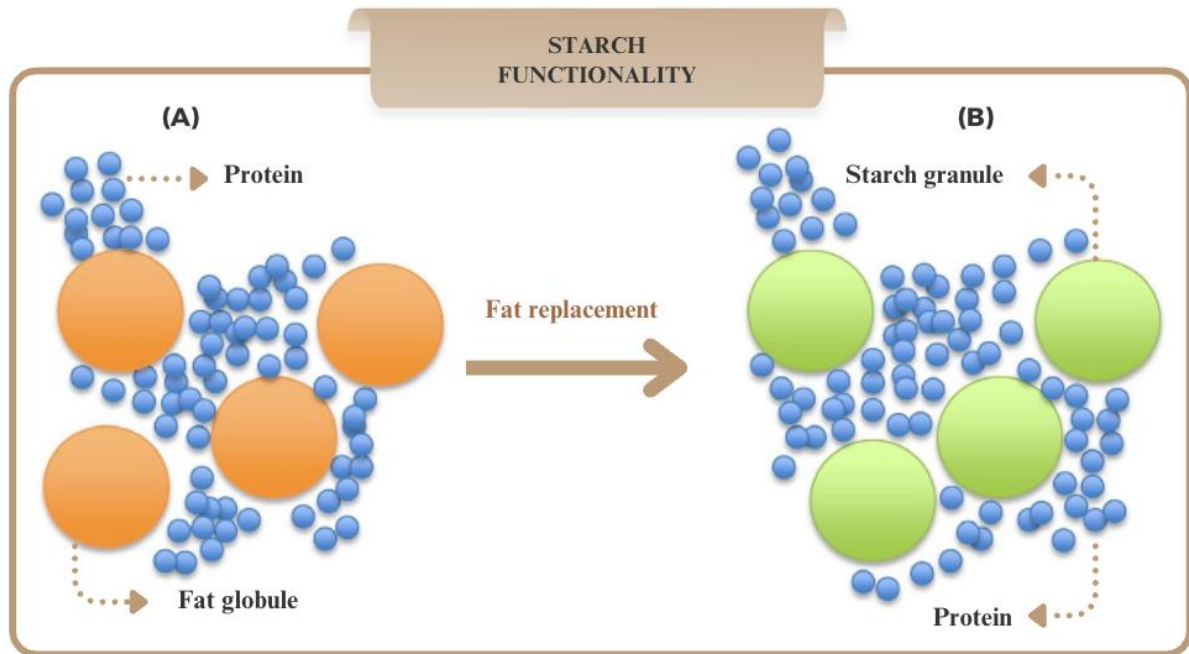


Figure 5. Schematic representation of starch functionality as a fat replacer. (A) Traditional system with fat globules (orange) dispersed within the protein matrix (blue). (B) System after fat replacement, where starch granules (green) substitute fat globules. Adapted from Chen et al., (2020)

3.3.Limitations of native starch compared to other fat replacers for ice cream applications

Despite the numerous functional properties of native starch for its application in food matrices, certain characteristics limit its applicability, including low thermal and shear resistance, as well as retrogradation (Hong et al., 2017). Additionally, native starch has limited industrial applicability, regardless of its source, as its granules swell and break easily when hydrated, reducing viscosity and forming a cohesive paste (Sahoré; Amani; Nemlin, 2005). Furthermore, it presents limitations such as susceptibility to pH variations, low paste clarity, high retrogradation, and degradation, affecting its efficiency as a fat replacer in frozen formulations (Bismark; Zhifeng; Benjamin, 2018).

To overcome these limitations, various structural modification strategies have been explored, including physical, chemical, and enzymatic treatments, which enhance thermal stability and functional properties of starches. Structural regulation through the control of hydrogen bond formation can optimize its water-binding capacity and improve its thermal stability, making it more suitable for product applications including ice cream (Yiu et al., 2008). Therefore, modified starches have superior performance in formulations that require greater thermal stability and controlled gelatinization (Chen et al., 2020). In addition, native starch also presents some disadvantages compared to other fat replacers, such as hydrocolloids and dairy proteins.

Hydrocolloids, such as carrageenan, guar gum, and xanthan gum, form three-dimensional networks that stabilize the liquid matrix, reducing ice crystal formation and enhancing creaminess in ice cream. Meanwhile, dairy proteins such as casein and whey protein contribute to emulsion stabilization and improve sensory properties. Compared to these hydrocolloids, modified starches provide advantages in texture formation and compatibility with complex food systems, adding body and elasticity to products. Additionally, resistant starches function as dietary fibers and modulate digestion, expanding their potential applications in health-oriented formulations. Blending these different fat replacers can be an effective strategy to optimize its functional properties, making it a more competitive fat replacer for frozen dessert applications (Goff and Hartel, 2013; Akbari, Eskandari, Davoudi, 2019; Zhao et al., 2023).

For instance, a study comparing ice cream with 5% fat to 10% fat control found that a mixture of hydrocolloids (basil seed gum and guar gum) had a synergistic effect, enhancing consistency and viscosity more than their performance. Reducing fat content to 5% increased melting rate and overrun. However, by raising the hydrocolloid content between 0.45- 0.55% the values of these parameters decreased (Javidi and Razavi, 2018). Thus, the ideal fat replacer depends on the desirable characteristics in the final product, requiring an integrated approach to maximize stability and sensory quality in ice cream formulations.

4. ADVANCES IN STARCH MODIFICATION TECHNIQUES FOR FAT MIMETICS IN ICE CREAM

4.1.Physical modification of starch (a green technique)

Physical modification methods have been widely accepted as a green, cost-effective, and safe approach to enhancing starch functionality, as they do not involve chemical reagents (Punia, 2020). These methods improve starch properties for certain applications without leaving chemical residues, making them environmentally friendly and appropriate for clean-label products (Punia, 2019; Park and Kim, 2021).

Therefore, starch can be physically modified using treatments that alter its structural and functional properties by applying moisture, heat, shear, or irradiation. These techniques are selected based on the desired application and modifies the characteristics of starch granules, notably increasing surface roughness, increasing amylose content, and decreasing water absorption capacity. As a result, starch solubility decreases while its water retention capacity increases (Punia, 2020; Goel et al., 2020; Ye et al., 2023).

Physical modification methods are commonly classified into thermal and non-thermal processes. Thermal methods include pre-gelatinization, annealing and heat-moisture treatment (HMT). These procedures involve the application of heat or moisture to induce structural rearrangements in the starch granules. Alternatively, non-thermal modifications include pulsed electric fields, high-pressure processing, ultrasonication, micronization and γ -irradiation, which can change starch properties while preserving more of its native structure (Sharanagat et al., 2023).

Nonthermal physical modifications can alter the morphology of starch granules, reduce their crystallinity, and break down molecular chains. Depending on the starch source and conditions of the treatment, these structural alterations usually lead to improved solubility and swelling capacity, decreased gelatinization temperatures and viscosity, and variable effects on in vitro digestibility (Wu et al., 2022).

For instance, over the last decade, High Hydrostatic Pressure (HHP) has gained attention as a sustainable technique applied for starch modification (Dominguez-Ayala et al., 2023). Starch samples are encapsulated and submitted to pressures ranging from 100 to 1000 MPa at room temperature for a specified duration (Almeida et al., 2023). Since it is a non-thermal process, HHP minimizes nutrient and functional component loss in raw materials, thereby preserving their properties (Wang et al., 2023). Pressurized starch may be used as a fat substitute because the starch granules, which are thought of as microparticles with a well-defined size distribution, may stimulate fat droplets.

4.2. Chemical modification of starch

When starches undergo chemical modification, reactions such as oxidation, etherification, esterification, phosphorylation (cross-linking), cationization, acid hydrolysis or modification with octenyl succinyl anhydride (OSA) can occur. These processes improve their potential as fat replacers by increasing the quantity of hydroxyl functional groups that are reactive on the structural backbone of starch (Chen; Kaur; Singh, 2018; Lin et al., 2024).

4.2.1. Oxidation

Oxidation is a type of chemical modification applied to starch, typically involving its reaction with oxidizing agents such sodium hypochlorite in regulated temperature, pH, and time conditions. This process mainly affects the C-2, C-3, and C-6 hydroxyl groups of the glucose units, converting them into functional groups such as carboxyl groups and carbonyl (aldehyde) (Tolvanen et al., 2009; Chen et al., 2015). These modifications result in significant changes to the starch physicochemical and structural properties, enhancing its functional performance and overcoming limitations associated with its native form.

Oxidation processes are generally categorized into semi-dry, dry and wet methods, depending on the volume of effluents produced (Tolvanen et al., 2009). Despite concerns regarding the environmental impact of these effluents, agents like sodium hypochlorite, sodium periodate, and hydrogen peroxide remain widely used. The effectiveness of oxidation is largely influenced by the accessibility of primary hydroxyl groups in the starch granules, which serve as reactive sites for the formation of carbonyl and carboxyl derivatives (Zhang et al., 2012; Chen et al., 2015).

Among the oxidation products, two well-known derivatives are carboxymethyl starch and dialdehyde starch. The latter is commonly obtained through selective oxidation at low temperatures (around 35 °C) over several hours, typically using sodium periodate (NaIO_4) to break α -1,4 and α -1,6 glycosidic linkages, introducing aldehyde functionalities into the starch backbone (Figure 6) (Kariuki et al., 2022).

In a study by Fasuan, Gbadamosi, and Akanbi (2018), different chemical modifications including oxidation, esterification, cross-linking, and osmotic treatment were applied to amaranth starch to evaluate their potential in fat replacement. Oxidized starch showed the highest content of alkenyl groups, indicating promising functionality for use as a fat mimetic in food applications.

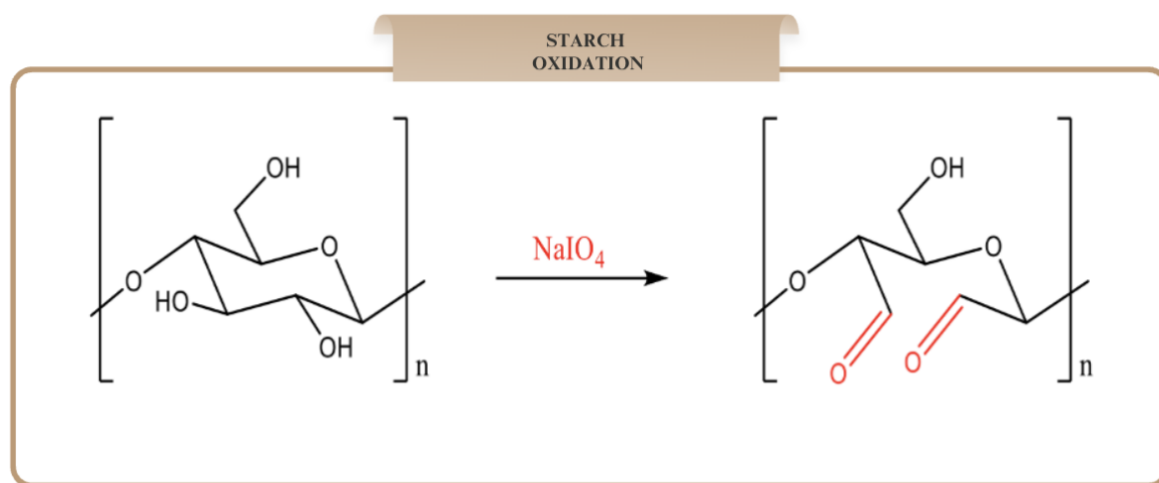


Figure 6: Starch oxidation with sodium periodate (El Farkhani et al., 2024).

4.2.2. Acid hydrolysis

Acid hydrolysis is a technique in which an acid solution is applied to native starch at temperatures below its gelatinization point. This process results in partial breakdown of the starch granules, leading to decreased paste viscosity and granule size. The hydrolysis predominantly affects amylopectin, causing extensive depolymerization and the formation of shorter linear chains that resemble amylose. These chains enhance the starch ability to form gels with increased firmness and structural integrity (Wang and Wang, 2001; Ulbrich et al., 2014). Common reagents used in starch modification include acids, acetates, hypochlorites, and phosphates. However, these chemical treatments often generate large volumes of waste, raising environmental concerns and necessitating the implementation of recycling or effluent treatment strategies.

4.2.3. Esterification

Esterification involves the substitution of the hydroxyl groups present in starch molecules with ester groups, through a reaction with compounds containing acid chlorides, acid anhydrides, or carboxylic acids, typically in the presence of an acid catalyst (Kim and Jung, 2022). This substitution alters the hydrogen bonding potential of amylose and amylopectin by reducing the number of free hydroxyl groups, thereby modifying its physicochemical behavior. One key effect of this modification is a reduction in the material affinity for moisture, which contributes to enhanced stability (Tian et al., 2018).

4.2.4. Etherification

Etherification is a chemical modification process in which the hydroxyl groups of the anhydroglucose units in starch are substituted with ether groups (St–OR) through a nucleophilic substitution reaction. This reaction typically involves the interaction between an alkoxide and an alkyl halide (Figure 7). Depending on the reagents and desired functional properties, etherified starches can be classified into four main categories: amphoteric, cationic, anionic, and non-ionic (alkyl) ethers derivatives (Akinterinwa et al., 2020). These modifications impart diverse functional characteristics to the starch, extending its use in industrial and food systems.

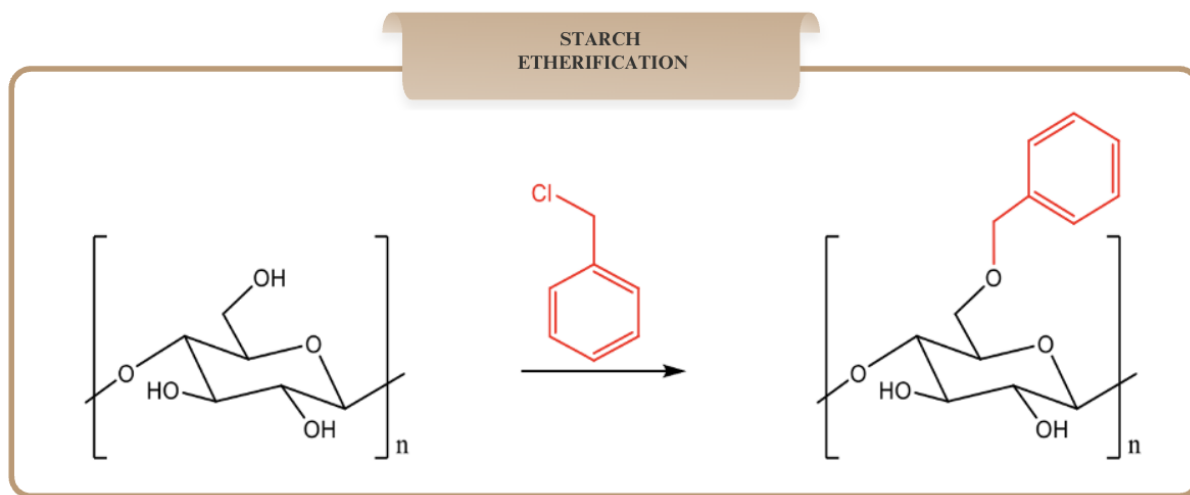


Figure 7: Etherification of starch (El Farkhani et al., 2024).

4.2.5. Cross-linking

Cross-linking is a common starch modification method that involves the formation of ether or ester linkages among hydroxyl groups in starch molecules. This process results in random intermolecular and intramolecular cross-links within starch granules, thereby improving their stability (Bagheri; Radi; Amiri, 2018). The main agents used in this process include, sodium tripolyphosphate, sodium hexametaphosphate, sodium trimetaphosphate, phosphorus oxychloride, citric acid, and adipic acid as presented in Figure 8 (Bangar et al., 2024).

Cross-linking enhances starch resistance to adverse conditions such as shear forces, high temperatures, and acidity, making it valuable for processed foods such as sauces, broths, and desserts due to its excellent thickening ability (Olayemi et al., 2021). Moreover, this process improves texture, enabling the development of creamier and more flavorful foods. Due to the covalent bonds formed, cross-linked starch is classified as a type 4 resistant starch (RS-4), which reinforces granule structure and preserves its integrity during cooking, resulting in greater resistance to enzymatic action (Klostermann et al., 2021; Ding et al., 2022).

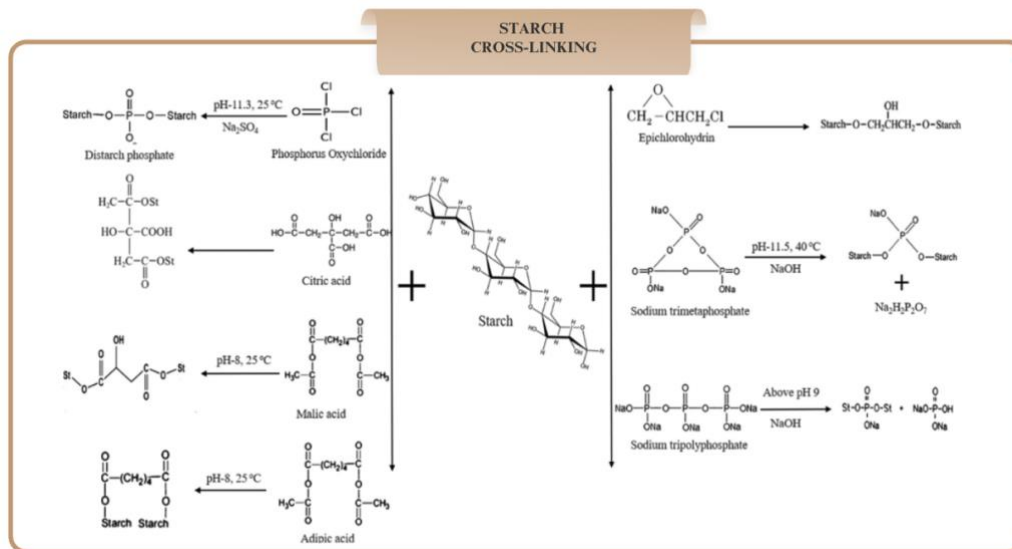


Figure 8. Mechanism of different starch cross-linking agents (Bangar et al., 2024).

Bagheri; Radi; Amiri (2018), evaluated the use of rice starch cross-linked with phosphoryl trichloride (POCl₃) as a fat replacer in creams, achieving 5%, 10%, and 15% fat reductions (w/w). Their results indicated that incorporating starch enhanced the hardness and freeze-thaw stability of the cream allowing up to 5% fat replacement without compromising sensory and physicochemical properties.

Additionally, cross-linked starches contribute to reducing the caloric value of food products, as they are less digestible than native starch and possess emulsifying properties, aiding in the transport of hydrophobic flavors and nutrients, thus improving overall product quality (Peng and Yao, 2017).

The researchers Surendra, Parimalavalli, Jagan (2018) formulated ice creams with different fat contents (6% and 1%) and incorporated various concentrations of citric acid cross-linked starch (1% and 2%). Their results demonstrated that adding 1% of starch improved the texture of the ice cream. This effect was also observed in the control ice cream, which contained 11% fat. However, the addition of 2% starch negatively impacted the melting stability and overrun of the ice creams. Similarly, replacing rice starch cross-linked with POCl₃ at concentrations of 5%, 10%, and 15% modified the textural properties and freeze-thaw stability. Increasing starch concentration resulted in greater firmness and freeze-thaw stability, whereas a 5% fat replacement, maintained creaminess.

4.3. Enzymatic modification of starch (a green technique)

Enzymatic modification has gained interest in both academia and the food industry because of its capacity to deliver desirable functional properties in a more sustainable manner (Punia, 2020). Enzyme-modified starch is considered healthier and safer for food applications, as it involves less severe reaction conditions (Obadi and Xu, 2021). The primary enzymes used in starch modification comprise transglycosylases (4- α -glucanotransferase, cyclodextrin glycosyltransferase and glucanotransferase) and glycosyl hydrolases (starch amylase, α -amylase and β -amylase). Free aglycones and sugar hemiacetals are produced when glycosidic bonds in glycosides are broken by glycosyl hydrolases, whilst transglycosylases facilitate the conversion of one glycoside into another (Bangar et al., 2022). Due to their lack of synthetic and artificial substances, these methods are known as "Clean Label" ingredients (Park and Kim, 2021).

Enzymatic modification presents multiple benefits compared to other modification methods. Due to its selectivity and specificity, enzymatic treatment minimizes the generation of secondary reactions, by-products and co-products. Conversely, acid hydrolysis, a form of chemical modification, induces random cleavage of glycosidic linkages in starch molecules, which hinders the recovery of acid from the final product. In enzymolysis, the reaction occurs under moderated conditions, and the activation energy is reduced, facilitating the conversion of the substrate into the product, with the possibility of enzyme recovery and reuse. When producing porous modified starch under sub-gelatinization conditions, this method is popular and recommended over chemical and physical methods. Thus, from an environmental and consumer perspective, enzymes are thought to be safer and healthier than chemical modification (Park et al., 2018; Park et al., 2018b). In addition, enzymatic starch modification provides additional benefits, such as higher purity, consistency, lower cost, and attractive functional properties (Park and Kim, 2021).

Moreover, it leads to the production of short-chain, linear amylopectin fractions with low molecular weights, increasing the resistant starch content and improving stability during freezing and thawing processes, as the branches of amylopectin inhibit the syneresis in the gel structure (Woo et al., 2021 ; Zhang and Bao, 2023). Enzyme-modified starches have also been shown to exhibit lower paste viscosity, differentiated rheological properties and increased digestibility and elasticity (Kim et al., 2017; Singla et al., 2020).

Enzyme-modified sweet potato starch has the potential to replace up to 20% of fat in ice cream formulations with low calories (Kale et al., 2020). This fat-reduced ice cream, in which fat was replaced with sweet potato starch modified by enzymes, achieved good organoleptic acceptance, resulting in reduced melting rate and overrun. The decrease in overrun was attributed to the viscous nature of sweet potato starch, which can hinder the mixture aeration. Simultaneously, the ice cream exhibited increased mix viscosity and higher total solids. The fat replacement with enzyme-modified sweet potato starch decreased the amount of fat in the ice cream from 9.85% to 7.9%, demonstrating the potential of enzyme-modified sweet potato starch as a fat substitute in ice cream formulations.

4.3.1. Maltodextrin

Maltodextrin is a D-glucose polymer, composed of α -(1,4) and α -(1,6) linkages, obtained through controlled hydrolysis of starch using acid and/or enzymatic processes. The enzyme commonly used to produce maltodextrin through enzymatic hydrolysis of starch is α -amylase (Figure 9) (Garnero, Aloisio, Longhi, 2013; Du et al., 2021). Maltodextrin composition includes 5–7% maltose and 2–3% glucose, and it can be produced as a hygroscopic white powder through spray drying. Maltodextrin has a subtle sweetness with almost neutral flavor, is highly soluble in water and easily disperses in aqueous solutions but poorly soluble in alcohol (Parikh; Agarwal; Raut, 2014). As a product of incomplete starch hydrolysis, maltodextrin has variable functional properties determined by factors such as average chain length and distribution of molecular weights, and the degree of branching of glucose polymers (Du et al., 2021). These characteristics make maltodextrin extensively used in the food industry, particularly as a fat replacer (Garnero, Aloisio, Longhi, 2013; Du et al., 2021).

For instance, a variety of commercial fat substitutes based on maltodextrin are supplied on the market, such as Oatrim-5, Oatrim (derived from oat starch), Paselli SA2 (derived from potato starch), Maltrin M040 (obtained from corn starch) and N-oil (derived from tapioca starch). Oatrim-5 combines oat β -glucan with maltodextrins from the same cereal, offering additional health benefits such as cholesterol reduction (Chavan; Khedkar; Bhatt, 2016). However, these substitutes have certain limitations, including low stability during freezing and

thawing, as well as sensitivity to extreme acidity and heat conditions, which may compromise their technological and sensory properties.

Research by Azari-Anpar et al (2017), found that the incorporation of maltodextrin (0, 1, and 2% w/w) and resistant starch (0, 1, and 2% w/w) in reduced-fat ice creams (4% fat content) was evaluated. The results indicated that concentrations above 1.5% of these ingredients led to a 45% increase in overrun, improving air incorporation and texture. Additionally, a significant increase in mixture viscosity was observed, rising from 748 cP to 1264 cP at the highest concentrations.

Moreover, Abd El-Khair and collaborators (2020) investigated the effects of replacing milk fat with either maltodextrin or inulin (at 2, 4, and 6% w/w levels) on the physicochemical and sensory characteristics of low-fat ice cream. The study found that formulations containing maltodextrin melted more slowly ($P \leq 0.05$) than those with inulin. Additionally, mixes with maltodextrin showed higher viscosity, owing to superior ability to form gel and bind water, which contribute to increased viscosity in ice cream.

The presence of maltodextrin in the ice cream mix leads to elevated viscosity, which restricts molecular mobility and hinders the uniform incorporation and distribution of air cells. This higher viscosity is likely a key factor contributing to the reduced whipping capacity of the mix, ultimately limiting its ability to incorporate air and resulting in lower overrun (Fernandes et al., 2017). These findings demonstrate the potential of maltodextrin as a structuring agent in low-fat formulations, directly influencing the rheological properties of ice cream.

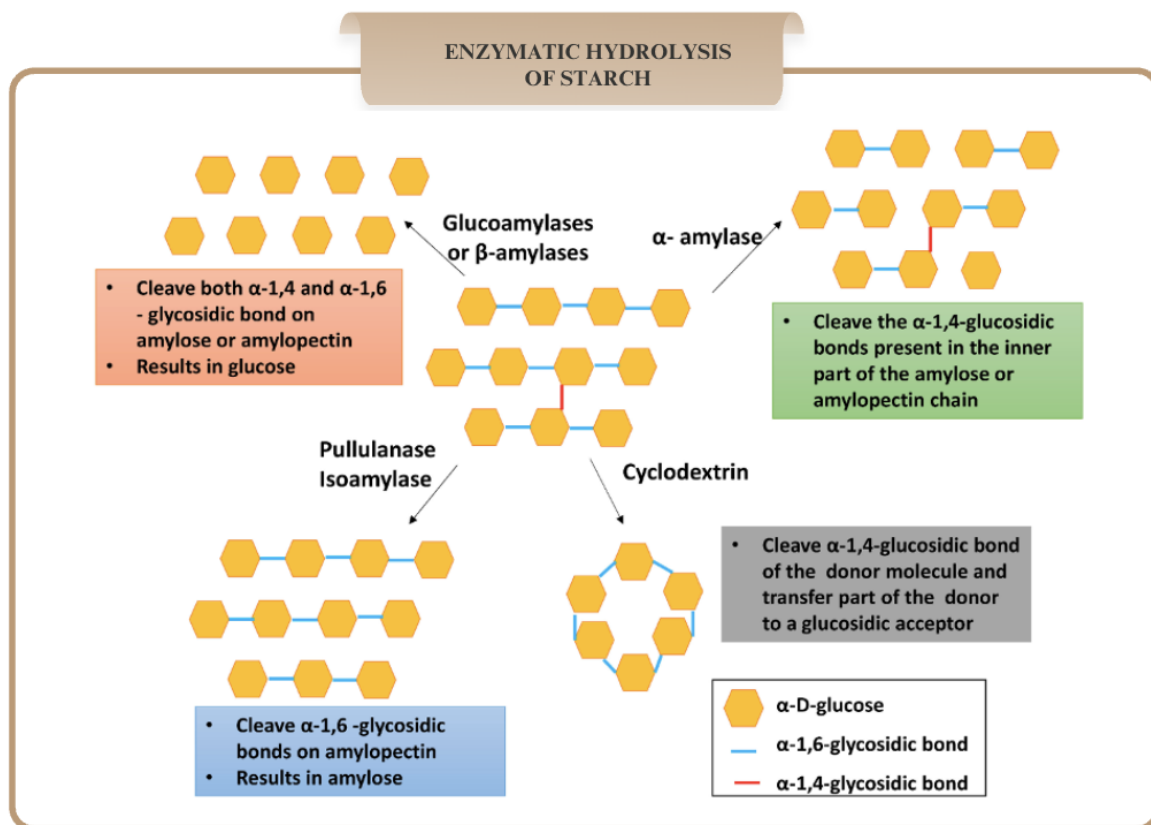


Figure 9: Enzymatic hydrolysis of starch (Amaraweera et al., 2021).

4.4. Starch nano-structuring

Recently, with the advancement of nanotechnology, research on nano-starch has intensified, highlighting its unique chemical properties, as well as its large surface area and

small size (Qiu et al., 2019). The shape and size of nano-starch granules can impact characteristics such as texture, flavor, appearance, and various functionalities (Dera and Teseme, 2020).

The production of starch nanoparticles is typically conducted by acid hydrolysis, utilizing the amylopectin present in starch. This process includes the conversion of the starch polymer structure into monomers, resulting in starch nanocrystals formation (Apostolidis; Stoforos; Mandala, 2023). However, physical methods such as high-pressure homogenization and ultrasound application attract attention as chemical residue-free techniques that effectively reduce starch particle size, making them promising alternatives for nanocrystal production (Bemiller and Huber, 2015; Altaf et al., 2022).

Lin and collaborators (2023) demonstrated that replacing fat with starch nanocrystals from chestnut, corn, and potato in varying proportions resulted in notable decrease in the melting rate of ice cream. The replacement proportions ranged from 0%–60% for chestnut starch, 20%–80% for corn starch, and 0%–80% for potato starch. This decrease was explained by the development of a three-dimensional network that hindered heat transfer inside the ice cream, thereby delaying its melting (Elleuch et al., 2011a). Additionally, observations revealed that ice cream viscosity directly influences its melting rate, with formulations with higher viscosity demonstrating greater resistance to melting (Akbari; Eskandari; Davoudi, 2019).

5. FUNCTIONS OF STARCH-BASED FAT MIMETICS IN LOW-FAT ICE CREAM

5.1. Effect on texture, rheology, creaminess, and melting properties

In low-fat ice cream formulations, various quality attributes, including hardness, are affected. Hardness and fat content are inversely correlated, meaning that softer ice creams typically contain higher fat levels, while firmer ones have lower fat content. This variation is due to increased ice crystal formation when fat is reduced, differentiating the product from traditional formulations (Akbari; Eskandari; Davoudi, 2019).

For instance, ice crystals larger than 50 μm confer a grainy texture, while those between 10 and 20 μm result in a smoother texture preferred by consumers. Additionally, ice crystal size influences ice cream shelf life, as recrystallization intensified by temperature fluctuations in freezers gradually increases crystal size (Marshall, Goff, Hartel, 2003; Eisner, Wildmoser, Windhab, 2005).

Aime and collaborators (2001) evaluated the replacement of fat with modified pea starch in vanilla ice creams with different fat levels: 0.4% fat-free, 2.5% low-fat, and 5% light, in contrast to a 10% full-fat control. Instrumental and sensory texture characteristics were analyzed. Instrumental firmness analysis revealed that lower-fat samples exhibited lower viscosity compared to the light and full-fat versions. However, the low-fat sample demonstrated a high consistency coefficient, resulting in firmness comparable to the full-fat ice cream. Sensory tests, in turn, did not identify significant differences among the samples, despite the fat-free formulation showing higher ice crystal formation. Rheological analysis indicated that higher consistency coefficients were associated with better mouth coating and increased apparent viscosity. Moreover, the perception of coldness remained constant across all formulations, despite expectations of reduced coldness with increasing fat content (Aime et al., 2001).

Similarly, Surapat and Rugthavon (2003), investigated the replacement of coconut milk fat with modified starch (MT-01 or α -starch). Fat levels were reduced between 1% and 8% and compensated by starch addition. The results indicated that fat replacement increased the

viscosity and resistance to deformation in ice cream. However, no significant alterations in melting rate or pH were identified in comparison to the control.

Lin et al (2023), modified the production sequence of starch nanocrystals by incorporating high-pressure homogenization followed by ultrasonication. The researchers then evaluated the effects of these nanocrystals as fat substitutes in ice cream. Three types of starch were used to generate nanocrystals using the modified sequence, namely, type A corn starch, type B potato, and type C chestnut. The application of starch nanocrystals as fat substitutes raised the viscosity of the ice cream mix after homogenization and aging, as the formed gel retained a considerable volume of water, thereby increasing the product's viscosity. Consequently, a higher starch concentration resulted in a stronger gel network within the system.

Fat replacement at levels of 20%-80%, 0%-60%, and 0%-80% with corn, chestnut, and potato starch nanocrystals, correspondingly, significantly reduced ice cream melting rate. This effect was due to the development of a three-dimensional structure that decreased transmission of heat inside the product, consequently slowing its melting process. However, ice cream formulated with corn starch nanocrystals exhibited the fastest melting rate, possibly due to the nearly spherical shape and small size of its particles. Melting resistance was also associated with viscosity, as more viscous formulations demonstrated greater resistance to melting. Regarding hardness, significant variations were observed among the different types of starch nanocrystals. Fat replacement with chestnut, potato, and corn starch nanocrystals resulted in maximum hardness values of 326.35 N, 210.02 N, and 118.71 N, respectively (Lin et al., 2023).

5.2.Effect on sensory properties

Aime et al. (2001) found that light ice cream containing 5% modified pea starch exhibited no significant differences in sensory attributes in contrast to the control. Nevertheless, in low-fat and fat-free samples with the same starch concentration, attributes such as mouth coating and smoothness were rated lower than in control ice cream. These results are consistent with Surapat & Rugthavon (2003) findings, which reports that reduced-fat coconut ice cream made with modified starch as a fat substitute did not affect color or flavor in contrast to the sample with full fat.

In ice cream recipes, maltodextrins are frequently used as fat substitutes. Fuangpaiboon & Kijroongrojana (2017) used commercial maltodextrins (DE 10) from Nutrition Sc Co. (Thailand) to analyze the effectiveness of several commercial fat substitutes based on protein and carbohydrates. Their findings indicated that using maltodextrin in place of 50% of the milk fat preserved sensory attributes comparable to the control sample containing 8% total fat. Furthermore, products formulated with maltodextrin exhibited enhanced mouth coating and a more intense flavor profile.

According to Abd El-Khair et al (2020), sensory evaluation of fresh ice cream samples revealed that the control formulation received slightly higher scores than the maltodextrin-treated samples. However, formulations containing inulin outperformed both the control and maltodextrin variants in terms of flavor. All levels of inulin inclusion led to improved flavor scores, with the highest rating at 45.37 for 4% of replacement. In contrast, Karaca et al (2009) reported that reducing fat content using carbohydrate-based fat replacers resulted in lower flavor scores compared to the full-fat control, highlighting the variability in sensory outcomes depending on the type and level of fat replacer used.

Surendra Babu et al (2018) carried out a study to investigate the effect of modified sweet potato starch cross-linked with citric acid as a fat replacer on the overall quality of low-fat ice creams. The findings indicated that, although the fat substitute partially affected the freezing

capacity of the product, the formulation containing 1% modified starch achieved sensory acceptance equivalent to the full-fat sample without compromising microbiological stability.

A sensory analysis comparing ice cream formulations containing 0% and 2.6% green banana biomass used as an unconventional starch-based fat replacer showed high levels of consumer acceptance. The average scores for color, appearance, creamy texture, vanilla flavor, sweetness, and global impression ranged between 7 and 9 on the hedonic scale, corresponding to “like moderately” to “like extremely,” and accounted for at least 82% of the responses. Similarly, consumption intention scores also fell within the 7 to 9 range, indicating a strong willingness to consume the product, from “I would eat this often” to “I would eat this whenever I had the opportunity” (Cardoso et al., 2023). These results reflect favorable sensory acceptance, as food products must achieve an acceptability index above 70% to be considered acceptable, according to Castro et al. (2007).

Lin et al (2023) explored the use of physically prepared starch nanocrystals (NCs) derived from corn (A-type), potato (B-type), and chestnut (C-type) starches as fat replacers in ice cream. The control sample, without fat replacement, achieved a high overall sensory score of 90.8. However, when fat was substituted with starch NCs, sensory scores declined proportionally with the increase in NC concentration, likely due to increased hardness. Among the tested formulations, ice cream with 20% fat replaced by corn starch NCs received sensory ratings similar to the control. This was explained by the spherical morphology of corn starch NCs, which can stabilize the oil–water interface and promote air incorporation, contributing to a softer texture and improved sensory quality.

In summary, studies demonstrate that starch-based fat substitutes hold significant potential for maintaining or even optimizing sensory attributes in reduced-fat ice creams. However, it is essential to consider their impact on technological properties such as freezing behavior and texture to develop well-balanced formulations that meet quality standards during storage.

5.3.Comparative effects of starch-based fat mimetics

Starch modifications have a direct influence on the effectiveness of fat replacers in ice cream formulations. Properties such as increased gelation, viscosity, and water retention capacity are crucial for replicating the technological and sensory effects of traditional fats. Potential uses for both native and modified starches to mimic these characteristics while addressing the demand for low-fat products with enhanced functionalities underscores the importance of research in this field. A comparative overview of the characteristics and applications of various starch-based fat mimetics in ice cream is summarized in Table 1.

Khan et al (2018) analyzed variables influencing texture, sensory characteristics, and melt resistance in low-fat and sugar-free ice cream formulations using response surface methodology. Their study found that the addition of 3% maltodextrin and 7% polydextrose increased ice cream overrun while maintaining its sensory and physicochemical characteristics. Additionally, the mouthfeel of reduced-fat ice cream was comparable to that of full-fat ice cream.

Shenana (2021) evaluated the partial replacement of buffalo milk fat with maltodextrin, modified starch, inulin, whey protein concentrate, and oat bran in ice cream formulations, standardizing the fat content at 2%. The results indicated that all formulations were well-received by sensory panelists, except for the control sample that did not contain fat replacers. Among the tested ingredients, maltodextrin and inulin exhibited the most favorable outcomes, yielding sensory scores similar to the full-fat ice cream.

Rolon et al (2017) investigated the impact of fat replacement with maltodextrin in vanilla ice cream. The formulations contained varying fat levels (6, 8, 10, 12, and 14%) and maltodextrin concentrations (0, 2, 4, 5, and 8%). During storage, physical and sensory characteristics were evaluated. The parameters analyzed included fat destabilization, melt rate, air incorporation, apparent viscosity, hardness, fat particle size, and consumer acceptance. A reduction in maltodextrin content and an increase in fat content resulted in destabilization, larger fat particles, and lower mix viscosity. Fresh samples did not differ significantly from those stored at -18°C for 19 weeks in terms of sensory acceptance. However, ice cream samples containing 8% fat and 6% maltodextrin, as well as those with 10% fat and 4% maltodextrin, exhibited a sharp decline in sensory attributes after storage.

Overall, the findings from these studies (Table 1) demonstrate the promising role of starch-based fat mimetics, particularly modified starches in maintaining or even enhancing the quality attributes of low-fat ice cream. These ingredients have shown effectiveness in improving texture, overrun, melt resistance, and sensory acceptance, making them valuable for developing healthier formulations. However, their impact may vary depending on interactions with other ingredients, concentration, and processing parameters. Continued research is needed for optimizing low-fat ice cream that align with both health and sensory acceptance.

Table 1. Influence of various starch-based fat mimetics in ice cream formulations.

Type/Source of starch	Type of modification	Main findings	Reference
Modified pea starch	Physical	The application of modified starch as a partial fat replacer in vanilla ice cream showed positive results in sensory acceptance tests.	Aime et al., (2001)
Maltodextrin and polydextrose	Chemical	The addition of 3% maltodextrin and 7% polydextrose proved to effectively replicate the mouthfeel characteristic of traditional full-fat ice cream, as well as providing volume to low-fat ice cream.	Khan et al., (2018)
Maltodextrin (STAR-DRI®)	Chemical	Minimal changes were observed in the sensory and physical characteristics of low-fat ice creams, whether fresh or stored, containing maltodextrin.	Rolon et al., (2017)
Wheat starch and amaranth	Chemical	2% w/w starch granules can replace up to 50% of milk fat.	Malinski et al., (2003)
Resistant corn starch	Chemical	2% w/w resistant starch led to the development of an ice cream with desirable overrun, first drop time, viscosity, melting rate, and acidity.	Azari-Anpar et al., (2017a)
Cross-linked rice starch	Chemical	An increase in firmness and freeze-thaw stability was observed, without compromising creaminess at 5% substitution.	Bagueri et al., (2018)
Maltodextrin, modified starch, inulin, oat powder, and whey protein concentrate powder		Samples with maltodextrin, followed by those with inulin, were chosen as the most effective treatment and achieved the highest panel scores, as did whole ice cream.	Abdou et al., (2021)

Debranched Waxy Rice Starches	Enzymatic	The apparent viscosity, consistency coefficient, zeta potential, emulsion stability and melting resistance were higher in the ice cream with fat substitution with fat-free debranched waxy rice starch than in the control ice cream.	Jin et al., (2024)
Cross-linked cassava starch	Chemical	The use of 10% modified cassava starch combined with 0.3% hydrocolloids and emulsifiers increased overrun, viscosity, melting percentage, and drip time in the ice cream formulations.	Marimon-Valverde et al., (2024)
Modified sweet potato starch	Chemical	The addition of a fat substitute (2%) decreased melting resistance and overrun in ice creams with reduced fat content.	Surendra Babu et al. (2018)
Green banana biomass (resistant starch)	n/a	The partial substitution of cream by green banana biomass effectively reduced the fat content of homemade ice cream.	Cardoso et al., (2023)
Green banana flour (resistant starch)	n/a	Green banana flour contributes dietary fiber and prebiotics to synbiotic ice cream, enhancing its nutritional and functional quality. The 4% level resulted in highest acceptability scores.	Prashanth et al., (2018)
Green banana flour (resistant starch)	n/a	Positive effects on acidity, moisture, ash, fat, and viscosity were observed with green banana flour addition, although it negatively affected color, melting characteristics and overrun.	Yangilar (2015)
Corn resistant starch (Hi Maize)	n/a	Replacing sheep's milk fat with resistant starch to produce sheep's milk ice cream proved to be an alternative capable of lowering the caloric value of the product.	Balthazar et al. (2017)
Corn starch (type A), potato (type B) and chestnut (type C)	Nanotechnology	The addition of starch nanocrystals as a fat replacers significantly increased hardness, viscosity, and melting behavior in low-fat ice cream, particularly when using corn starch nanocrystals.	Lin et al (2023)
Sweet potato starch	Enzymatic	Fat content reduced from 9.85% to 5.79% as the level of modified starch increased. Results indicate that enzyme-modified sweet potato starch can be used at concentrations of up to 20% as a fat replacer in ice cream formulations.	Kale et al 2020

6. CONCLUSION

Starch-based fat substitutes represent a promising alternative for the development of low-fat ice creams, addressing the growing demand for healthier products. Advances in starch modification techniques, such as nanotechnology and sustainable enzymatic treatments, have significantly enhanced their physicochemical, sensory, and nutritional properties. These innovations enable starch-based substitutes to replicate desirable characteristics such as creaminess, texture, and stability, which were traditionally provided by fats. Among these substitutes, resistant starch stands out for its potential to reduce glycemic impact while offering functional benefits, including increased dietary fiber content and improved metabolic responses, making it a strategic ingredient for the formulation of functional ice creams.

However, challenges remain, such as achieving a balance between taste, cost-effectiveness, and industrial feasibility. Future research could explore the combination of starch-based fat substitutes with other plant-derived ingredients to enhance their versatility and functionality. Furthermore, optimizing production processes to mitigate environmental impact is crucial to ensuring the scalability and commercial viability of these solutions. In this context, starch-based fat substitutes hold transformative potential in the ice cream sector, contributing to the development of healthier and more sustainable products.

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DECLARATION OF COMPETING INTEREST

The authors have no conflicts of interest.

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CAPÍTULO II

BIOMASSA DE BANANA VERDE COMO MIMÉTICO DE GORDURA NA QUALIDADE FÍSICO-QUÍMICA E SENSORIAL DO SORVETE DE COCO

GREEN BANANA BIOMASS AS A FAT MIMETIC ON THE PHYSICOCHEMICAL AND SENSORY QUALITY OF COCONUT ICE CREAM

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ABSTRACT

The increasing demand for healthier foods has driven the development of formulations with reduced fat content. In ice cream, fat plays a crucial role in texture, stability, and sensory acceptance. This study aimed to investigate the impact of replacing cream with green banana biomass (GBB) in coconut ice cream at substitution levels of 0%, 25%, 50%, 75%, and 100%. The physicochemical, microbiological, and sensory properties were analyzed. Substitution of up to 25% of fat with GBB did not significantly affect sensory characteristics in terms of appearance, texture, and flavor. Increasing levels of GBB led to reduced overrun and luminosity, as well as increased firmness and slower melting rate. Additionally, formulations containing 75% and 100% GBB exhibited unsaturated fatty acids, which could provide nutritional benefits. These findings underscore the viability of GBB as a fat replacer in ice cream, improving thermal stability and nutritional value without compromising sensory quality at lower substitution levels.

KEYWORDS: Resistant starch, Fat reduction, Functional ice cream, Thermal stability, Unripe banana, Unconventional ingredient.

1. INTRODUCTION

Ice cream is a widely appreciated frozen dessert due to its sensory characteristics such as creaminess and flavor (Soares et al., 2024; Tolve et al., 2024). Its traditional formulation includes water, milk powder, cream, sugar, stabilizers, and emulsifiers, with fat playing a crucial role in determining the product's sensory quality by influencing texture and mouthfeel (Kasapoglu et al., 2023; López-Martínez; Moreno-Fernández; Miguel, 2021). The fat content in ice cream typically ranges from 10% to 16% and directly affects its quality and acceptance throughout production, storage, and commercialization (Pei et al., 2025).

Although milk fat which content saturated fat is essential for these sensory characteristics, excessive intake of saturated fat through the consumption of different products including ice cream, has been associated with various health concerns such as obesity, cardiovascular diseases, and type 2 diabetes (WHO, 2023; Balivo; D'errico; Genovese, 2024). This scenario has encouraged both consumers and manufacturers to seek alternatives with lower fat content to improve the nutritional profile of ice cream (Genovese et al., 2022). In this context, replacing traditional fats with healthier ingredients emerges as a promising strategy for the food industry.

Green banana biomass (GBB) has gained attention in the scientific literature due to its high content of resistant starch (type III) and dietary fiber. These components provide prebiotic properties and offer health benefits such as improved glycemic and lipid control, and cholesterol reduction (Cassettari et al., 2019; Marchioretto et al., 2024). Additionally, GBB stands out as a sustainable ingredient, as its production/consumption may help reduce banana waste which is a common issue in many producing regions (Pivetta et al., 2020; Feitosa et al., 2023). Thus, GBB represents an ecological and functional alternative for various food formulations (Auriema et al., 2022; de Oliveira et al., 2024).

While GBB has been explored in a range of food applications including vanilla and passion fruit ice creams, and frozen yogurt (Cardoso et al., 2023; Aragão et al., 2018; Soares et al., 2024), its use in coconut milk-based ice cream has not yet been investigated. Coconut milk is widely used in plant-based foods, it has a relatively high fat content (Wu et al., 2023; Chen et al., 2024) presenting an additional challenge in formulating low-fat ice creams without compromising desirable sensory characteristics. In this sense, this work is pioneering in investigating GBB as a fat replacer in coconut milk ice cream.

Given this context, the present study aims to evaluate the effect of replacing cream with GBB in different proportions (0%, 25%, 50%, 75%, and 100%) in coconut ice cream formulations, considering the physicochemical, microbiological, and sensory characteristics.

2. MATERIALS AND METHODS

2.1. Raw materials

The bananas (Prata cultivar) were harvested at the green peel maturity stage with similar diameters, obtained from an organic family farmer in Seropédica, Rio de Janeiro, Brazil (22° 44' 38" S, 43° 42' 28" W). They were stored at 25 °C until processing. The ingredients for ice cream formulations included coconut milk (20g/100g total fat), skimmed milk powder, cream (20g/100g total fat), vanilla extract, sugar, and emulsifier (23g/100g total fat). These ingredients were purchased from a supermarket in Campo Grande, Rio de Janeiro, Brazil. All ingredients were stored at room temperature until use in the sample preparations.

2.2. Mixture design

It was applied a mixture constrained design, with two components (X_1 : cream and X_2 : GBB), both accounted 24.5% of ice cream. The remaining ingredients were kept constant as observed in Table 1. The minimum and maximum limits for each component were established based on preliminary experiments. The response variables included: pH, titratable acidity, total

soluble solids, color, firmness, overrun, melting test, fatty acid profile, microbiological quality, and sensory profile. The data were fitted to a linear polynomial model (Equation 1).

$$Y_i = \beta_1 X_1 + \beta_2 X_2 + \beta_{12} X_1 X_2 + \varepsilon_{ijk} \quad (1)$$

Where: X_1 : cream percentage; X_2 : GBB percentage; β_1 and β_2 : linear coefficients of the two components; β_{12} : interaction coefficient or quadratic term in the mixture design model; Y_i : response variables to be optimized.

Table 1. Composition of ice cream formulations with different proportions of GBB.

Formulations	Ingredients (%)							Total
	Coconut milk	Skimmed milk powder	Sugar	Emustab	Vanilla extract	Cream	GBB	
0% GBB	49.63	6.17	12.30	6.17	1.23	24.50	0.00	100
25% GBB	49.63	6.17	12.30	6.17	1.23	18.375	6.125	100
50% GBB	49.63	6.17	12.30	6.17	1.23	12.25	12.25	100
75% GBB	49.63	6.17	12.30	6.17	1.23	6.125	18.375	100
100% GBB	49.63	6.17	12.30	6.17	1.23	0.00	24.50	100

2.3. Preparation of GBB

The GBB was prepared based on the methodology adapted from Tinoco et al. (2022). Initially, 1 kg of green bananas was sanitized in a sodium hypochlorite solution (200 ppm) for 15 minutes and then rinsed with distilled water. The bananas were cooked for 15 minutes in an electric pressure cooker (Philco, Manaus, Brazil) using 1.5 L of distilled water. After cooking, the bananas were peeled and processed in a blender (Oster, São Paulo, Brazil) with the addition of 225 mL of distilled water, until a creamy and homogeneous paste was obtained. The GBB was stored at 4 °C until ice cream formulations were made on the same day.

2.4. Quality analysis of GBB

Moisture content was determined according to the method described by the AOAC (2010); the samples were heated in an oven at 105 °C until achieving a constant weight. The protein, lipid, and ash contents were analyzed following the methods described by AOAC (2010). The pH was measured using a digital benchtop pH meter (PHS-3E, Brazil), as described by Anyasi et al. (2015). Titratable acidity was determined by direct titration using a standardized NaOH solution (0.1 mol/L), following the AOAC (2010) methodology. Total starch was quantified by acid hydrolysis, according to the methodology described in the ASEAN Manual of Food Analysis (2011).

2.5. Ice cream preparation

The tested ice cream formulations are described in Table 1. Initially, coconut milk, skimmed milk powder, sugar, and stabilizer were transferred to a sanitized 2L pan and gently mixed using a silicone spatula. The mixture was subjected to pasteurization and homogenization by heating on an induction stove (Philco, Manaus, Brazil) at 80 °C for 20 minutes. After pasteurization, heavy cream was incorporated into the mixture, which was then transferred to a 1L glass container with a lid and stored under refrigeration at 4 °C for 8 hours for maturation. After this period, the GBB was added to the formulations at 0% (control), 25%, 50%, 75%, and 100%, as shown in Table 1. Then, the mixtures were homogenized in a blender (Oster, São Paulo, Brazil) for 1 minute. Subsequently, the mixtures were frozen at -5 °C in a 1 L household ice cream machine (Tramontina, Breville Express, Brazil). Finally, the ice cream was packed in sterilized 130 mL plastic containers with lids and stored at -18 °C.

2.6. Ice cream quality analysis

The total soluble solids (°Brix) were evaluated after melting the samples for 1 hour at 24 °C. For this purpose, a portable refractometer model RT-280 (Instrutherm, São Paulo, Brazil) was used. The pH of the melted ice cream samples was determined using a previously calibrated pH meter (PHS-3E, Brazil) (Singo and Beswa, 2019). Titratable acidity was measured by titration with a standardized 0.1 mol/L NaOH solution (AOAC, 2010). The overrun (which represents the air incorporation into the ice cream) was calculated based on the difference between the weight of the initial mix and the weight of the hardened ice cream, considering a fixed volume of 130 mL. The overrun was calculated using Equation 2 (Jing et al., 2022).

$$\text{Overrun (\%)} = \frac{\text{Weight of mix} - \text{Weight of ice cream}}{\text{Weight of ice cream}} \times 100\% \quad (2)$$

The color measurement was taken 24 hours after the ice cream production by using a calibrated colorimeter (BrasEq, MiniScan EZ, São Paulo, Brazil), configured with the coordinates L (luminosity), a (red/green component), and b* (yellow/blue component). Based on the color coordinates (L^* , a^* , and b^*), the color difference (ΔE^*), whiteness index (WI) and the color saturation or chroma (C^*) were calculated using Equations 3, 4 and 5.

$$\Delta E^* = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2} \quad (3)$$

$$WI = \sqrt{(100 - L^*)^2 + (a^*)^2 + (b^*)^2} \quad (4)$$

$$C^* = \sqrt{(a^{*2} + b^{*2})} \quad (5)$$

Texture analysis was carried out by measuring the instrumental firmness of the ice cream samples using a texture analyzer (TA XT Plus®, Extralab, Brazil). Measurements were performed at a temperature of 20 °C, 10 minutes after the samples were removed from the freezer (Balivo et al., 2024). A stainless-steel cylindrical probe with a diameter of 5 mm, a penetration depth of 10 mm, and a trigger force of 30 kg was used. The test parameters included a pre-test speed of 5 mm/s, a test speed of 5 mm/s, and a post-test return speed of 5 mm/s. The firmness of the sample was determined by the maximum force required for its compression (N). Data collection was performed using the Exponent Lite® software.

2.6.1. Melting test

The melting test was performed based on the methodology adapted from Fiol et al. (2017). A laboratory ring affixed to a stand was positioned above a beaker containing a wire mesh screen. Ice cream samples (130 mL), previously stored at -18 °C for 24 hours, were individually placed on the mesh for monitoring melt behavior. A 250 mL beaker was positioned underneath to collect the melted liquid. The entire setup was placed on an analytical balance to record the mass loss of the ice cream every 10 minutes at a controlled temperature of 25 °C for 60 minutes.

2.6.2. Fatty acid profile

Lipid extraction from the ice cream was carried out based on the methodology adapted from AOAC (2010). Fatty acids quantification was performed using internal standardization with methyl undecanoate as the standard. The chromatographic conditions and methodology applied followed the parameters described by De-Oliveira et al. (2020).

2.6.3. Microbiological analysis

Microbiological analysis was carried out to ensure compliance with the standards established for edible ice cream, as defined by Normative Instruction No. 161 of July 1, 2022 (Downes and Ito, 2001). The presence of Salmonella spp. was assessed using XLD agar

(Himedia, Brazil). Quantification of coagulase-positive *Staphylococcus* spp. was performed using Baird-Parker agar (Isofar, Rio de Janeiro, Brazil). Enumeration of colonies from the Enterobacteriaceae family was conducted using VRBG agar (Himedia, Brazil). All plates were incubated at 35 °C for a minimum of 24 hours.

2.6.4. Sensory analysis of coconut ice cream

Sensory analysis was conducted using the multiple comparison test as described by Meilgaard et al., (2016). The sensory evaluation study was previously submitted to and approved by the Human Research Ethics Committee of the Federal Rural University of Rio de Janeiro under protocol number 82003624.1.0000.0311. The sensory panel consisted of eight semi-trained judges from the Department of Food Science and Technology of the same institution. Evaluated sensory attributes included appearance (color and visual ice crystals on the surface), flavor (coconut flavor and sweetness), and texture or mouthfeel (creaminess, ice crystals mouthfeel, fatty mouthfeel, and spoonability).

Samples were individually prepared and packaged in 30 mL containers, coded with random three-digit numbers, and frozen at -18 °C for 24 hours. Each panelist received all six samples simultaneously, including the control (0% GBB). The order of sample presentation was randomized across sessions and participants. Between samples, panelists performed palate cleansing with mineral water. The tests were conducted in individual booths under standardized white lighting to minimize external interferences. Evaluations were recorded on a 9-point numerical scale, ranging from “extremely better than the standard” to “extremely worse than the standard,” with the midpoint (5) corresponding to “equal to the control.”

2.7. Statistical analysis

Statistical analysis was performed using analysis of variance (ANOVA), followed by Tukey’s test for multiple mean comparisons ($p \leq 0.05$). Comparisons between the standard formulation and the others were carried out using Dunnett’s test. The effects of cream and GBB on the response variables were evaluated using linear and quadratic regression models. For each variable, the selected model was which presented the highest adjusted coefficient of determination (adjusted R^2) and no significant lack of fit for residual. All analyses were performed using R software.

3. RESULTS AND DISCUSSION

3.1. Chemical composition of GBB

The GBB samples exhibited a moisture content of $84.89 \pm 0.75\%$ (mean $\pm$ standard deviation), along with low protein (3.11 ± 0.24 g/100g) and lipid (1.55 ± 0.23 g/100g) levels. The ash content was 0.49 ± 0.03 g/100g. These values are consistent with those reported in previous studies conducted by Auriema et al. (2022) and Tinoco et al. (2022).

The GBB also showed an acidic pH (5.09 ± 0.02) and low titratable acidity ($0.14 \pm 0.02\%$), along with a total starch content of 15.99 ± 0.78 g/100g. Similar results were described by Dinon et al. (2014) and Auriema et al. (2022), who reported carbohydrate levels in GBB ranging from 19.43 to 24.70 g/100 g. This starch concentration may be attributed to the limited enzymatic conversion of this polysaccharide into simple sugars such as sucrose, fructose, and glucose compounds, which are responsible for the sweetness of ripe bananas (Zhu et al., 2018).

3.2. Physicochemical quality of ice cream

A reduction ($p \leq 0.05$) in total soluble solids (TSS) was observed with the increment of GBB (Table 2). This can be attributed to the fact that the GBB used was obtained from fully unripe bananas, with limited enzymatic conversion of starch into simple sugars such as glucose,

fructose, and sucrose. Previous studies have also reported that ice cream with GBB presented lower TSS values compared to the control, due to the high content of resistant starch in the biomass (Soares et al., 2024; Aragão et al., 2018).

The ice cream showed pH values close to neutral, suggesting low acidity. The control treatment (0% GBB) had the highest pH (6.98 ± 0.01), which differed significantly ($p \leq 0.05$) from formulations with the 25%, 50%, and 100% GBB. Titratable acidity was higher ($p \leq 0.05$) in the 25% and 100% GBB treatments, which may be due to the presence of phenolic compounds and organic acids found in GBB, as well as potential interactions of these compounds with the protein and lipid matrix of the ice cream. The acidity is important because it can affect emulsion stability and the sensory perceptions (Sadler; Murphy, 2010).

Regarding overrun, replacing of up to 25% of the cream with GBB did not affect ($p > 0.05$) air incorporation (0% GBB 30.67 ± 0.36 and 25% GBB 30.47 ± 1.40). However, full replacement of cream with GBB resulted in a lower overrun, possibly due to increased viscosity of the mixture caused by the high starch and soluble fiber content of the biomass. The viscosity of the ice cream mix directly influences bubble formation and stability during whipping, with thicker formulations typically incorporating less air (Goff and Hartel, 2013).

The overrun may also be related to the nature of the ingredients used, e.g. cow milk proteins like casein and whey, which play a key role in foam stabilization and lipid phase emulsification, ensuring a more aerated ice cream structure. On the other hand, coconut milk has a different lipid profile, being rich in medium-chain saturated fatty acids, which exhibit distinct crystallization and emulsification properties than milk. Furthermore, the low protein content of coconut milk reduces foaming capacity, contributing to lower overrun and a denser texture (Clarke, 2012; Goff and Hartel, 2013).

The overrun in the present research were lower than those reported by Soares et al. (2024) (91.30% to 95.30%) and Aragão et al. (2018) (45.10% to 61.50%). These discrepancies could be attributed to several factors, including differences in formulation, biomass processing, banana cultivar, and the type of emulsifier used in the mix. Additionally, freezing methods and air incorporation rates during whipping are crucial variables in the development of the ice cream aerated structure. Previous studies have also emphasized the role of hydrocolloids in air retention, highlighting the need to investigate the contribution of polysaccharides in this aspect (Liu; Sala; Scholten, 2023).

Another aspect that may influenced on overrun is the interaction between structural components of the ice cream. The starch in GBB may act as a thickening agent, altering the colloidal matrix and reducing air diffusion in the mix. Moreover, the presence of fibers may modify the rheological properties of the ice cream, affecting air retention capacity and promoting a creamier texture (Bahramparvar; Mazaheri Tehrani, 2011; Amador; Hartel; Rankin, 2017). Thus, for future applications of GBB in ice cream formulations, it would be relevant to evaluate the effect of different biomass pre-treatment techniques, such as enzymatic starch modification or the combination with alternative stabilizers, to optimize texture and air incorporation.

The partial substitution of cream with GBB can be feasible without significantly compromising air incorporation and the structural quality of the ice cream. However, full replacement may require formulation adjustments to compensate for the lower emulsifying and foaming capacity of the coconut milk and biomass matrix. Future studies may explore synergies between GBB and various natural emulsifiers and stabilizers to improve the final product quality.

Table 2. Physicochemical characteristics of ice creams containing different proportions of GBB

Formulations	Soluble solids(oBrix)	pH	Titrateable acidity	Overrun (%)	Firmness(N)
0%_GBB	30.83 ± 0.58 a	6.98 ± 0.01 a	0.24 ± 0.02 ab	30.67 ± 0.36 a	15.99 ± 7.55 c
25%_GBB	29.97 ± 0.15 ab	6.85 ± 0.05 b	0.28 ± 0.01 a	30.47 ± 1.40 a	43.77 ± 10.48 b
50%_GBB	29.67 ± 0.29 b	6.80 ± 0.08 b	0.22 ± 0.01 b	22.14 ± 0.34 b	60.71 ± 23.88 a
75%_GBB	28.90 ± 0.17 b	6.87 ± 0.01 ab	0.28 ± 0.04 ab	21.99 ± 1.32 b	58.28 ± 26.34 a
100%_GBB	27.33 ± 0.58 c	6.85 ± 0.02 b	0.28 ± 0.03 a	18.47 ± 0.53 c	49.11 ± 23.57 ab

Mean ± SD (n = 3). Different letters in the same column indicate statistically significant differences between formulations ($p \leq 0.05$), as determined by Tukey's test.

3.3. Color

A decrease in luminosity (L^*) was observed ($p \leq 0.05$) with the increment of GBB, with the 0% GBB formulation presenting the lightest appearance (92.32 ± 0.18) (Fig. 1A). This reduction in lightness may be attributed to the naturally brownish color of GBB, possibly due to the presence of phenolic compounds prone to oxidation and enzymatic browning reactions (Yangilar, 2015; Aragão et al., 2018).

Regarding WI in Figure 1B, it was observed a significant decreasing with increasing levels of GBB, being more pronounced in the formulations containing 75% (82.42 ± 0.35) and 100% GBB (81.89 ± 0.49), suggesting a shift to more yellowish or brownish tones. Color saturation (Cr^* , Fig. 1C) exhibited a similar trend, with a progressive increase in chromaticity, indicating more intense colors in formulations with higher biomass content. This effect may be related to the concentration of natural pigments in green bananas, which become more prominent as the cream is replaced (Aragão et al., 2018; de Oliveira et al., 2024).

The ΔE^* (Fig. 1D) increased ($p \leq 0.05$) with the increment of GBB. Higher ΔE^* values indicate perceptible changes in product color, which could directly impact consumer sensory acceptance. Similar results using green banana-based ingredients in food formulations. For instance, a study using green banana pulp flour in ice cream found negative a^* values, indicating a greenish hue, while L^* and b^* values were similar to those observed in the present study, reinforcing the impact of banana derived ingredients on color modification (Yangilar, 2015).

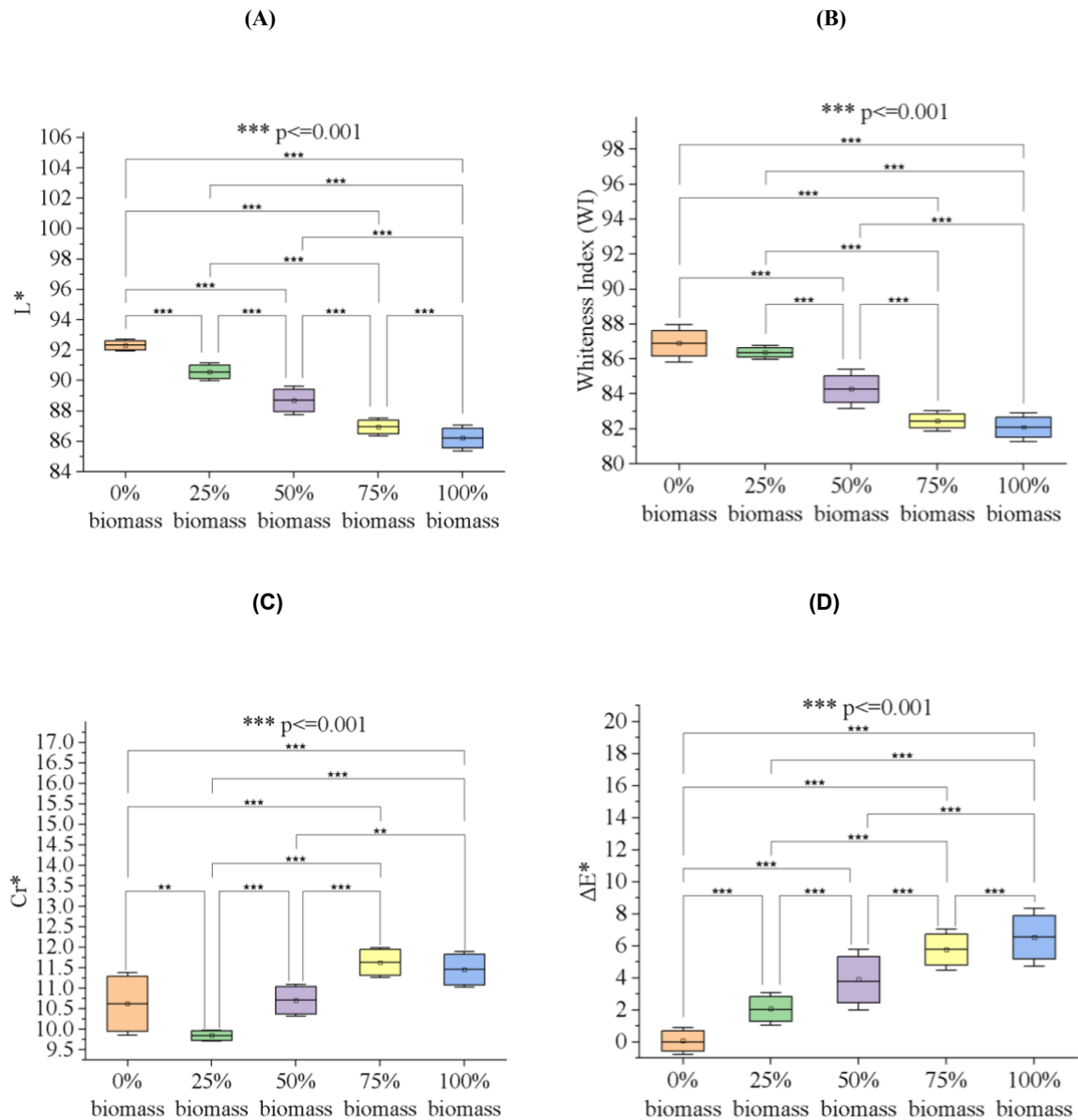


Fig. 1. Color measurements luminosity (L) (A), whiteness index (WI) (B), color saturation (Cr*) (C), and total color difference (ΔE^*) (D) of ice cream with different proportions of GBB. Statistically significant data at significance levels of 0.01 (**) and 0.001(***)

3.4.Firmness

The 0% GBB formulation exhibited the lowest firmness (15.99 ± 7.55 N) compared to the others ($p \leq 0.05$). Meanwhile, formulations with 50% (60.71 ± 23.88), 75% GBB (58.28 ± 26.34) and 100% GBB (49.11 ± 23.57) showed similar firmness among them ($p > 0.05$), as did the samples with 25% (43.77 ± 10.48) and 100% GBB (Table 2).

These findings are consistent with those reported by Fuangpaiboon and Kijroongrojana (2017), who observed that treatments using carbohydrate-based fat replacers (such as inulin, maltodextrin, and modified tapioca starch) in coconut milk-based ice creams resulted in greater firmness compared to the control. Milk fat plays a fundamental role in ice cream texture, being inversely related to firmness. Lower fat content tends to increase ice crystal formation, resulting

in a harder texture. Consequently, low-fat ice creams are expected to be firmer than those with higher fat content, such as those made with whole milk (Akbari et al., 2019).

3.5. Melting behavior

The formulations with 0% and 25% GBB melted completely within 60min, contrary to those with higher GBB (50%, 75%, and 100%) which showed lower mass loss (Fig. 2a and b). The increase of GBB led to a slower melting process of the ice cream. Similar results were reported by Soares et al. (2024) and Aragão et al. (2018), who observed that ice creams with higher levels of GBB exhibited lower melting rates, suggesting that the biomass components have a positive effect on the product thermal stability.

However, Cardoso et al. (2023) reported that using GBB as a partial fat substitute in homemade vanilla ice creams resulted in a higher melting rate, attributing this effect to lower air incorporation (overrun).

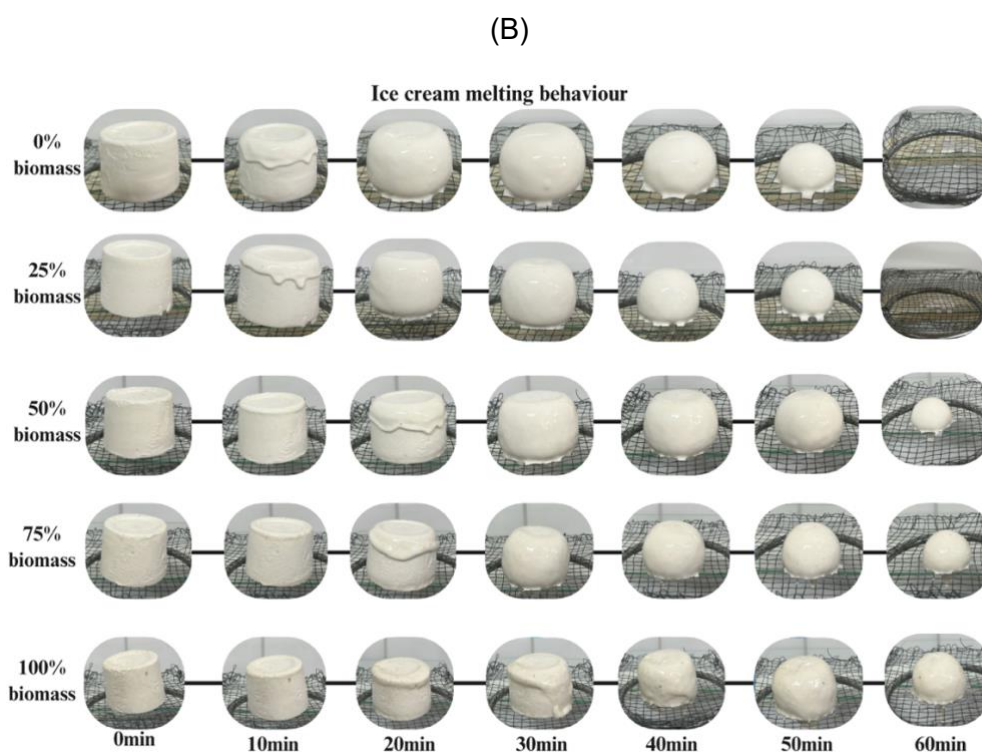
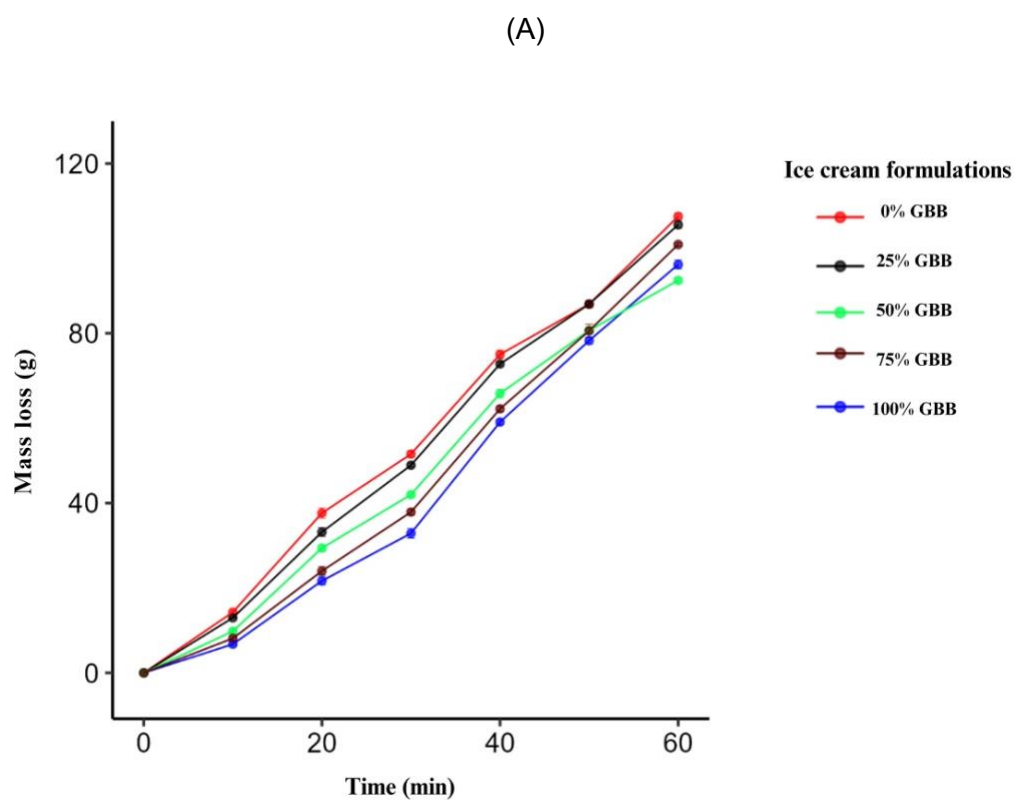


Fig. 2. Mean mass loss values of ice cream formulations with different proportions of green banana biomass (A). Melting behaviour of ice cream formulations with different concentrations of green banana biomass over time (B).

Although it is frequently reported that the GBB incorporation in ice cream led to higher melting rates, the opposite behavior of the present study may stem from GBB's high water-holding capacity, which helps create a denser, more solid ice cream structure. Water retention plays a crucial role in managing free water release during melting, enhancing product stability. A stable fat crystal network and its interaction with the aqueous matrix likely slowed the melting process, enabling a gradual water release (Liu; Sala; Scholten, 2023; Amador; Hartel; Rankin, 2017).

Moreover, the viscosity, gelling properties, and water-holding capacity of resistant starch are essential for restricting ice crystal mobility, making ice creams more resilient to temperature changes, which is an advantage for storage and transport (Elleuch et al., 2011). The findings of Rezaei et al. (2015) found that frozen soy yogurt with higher resistant starch content exhibited a slower melting process.

3.6. Fatty acid profile

The primary fatty acids identified in all formulations included lauric acid (C12:0), myristic acid (C14:0), and palmitic acid (C16:0). Among lauric acid (C12:0) the most predominant, reaching 40.11% in the 0% biomass sample. However, changes were observed ($p \leq 0.05$) in the content of fatty acids, particularly in medium-chain fatty acids (MCFAs), such as C8:0 (caprylic acid) and C12:0. Replacing 50% to 100% of fat with GBB significantly reduced C8:0 levels ($p \leq 0.05$) compared to 0% to 25% replacement. In contrast, levels of C10:0 (capric acid) and C14:0 showed no variations ($p > 0.05$), indicating that fat substitution did not affect the composition of these fatty acids among formulations (Table 3).

Additionally, higher GBB formulations showed the highest levels of C16:0 (palmitic acid), C18:1 n9c (oleic acid) and C18:2 n6c (linoleic acid). Notably, C16:1 cis (palmitoleic acid), absent in formulations with no or low GBB content, was only detected in the 75% and 100% biomass formulations, suggesting that fat replacement introduced unsaturated fatty acids into the ice cream matrix.

The quality of ice cream is strongly influenced by the fatty acid composition and the crystallization behavior of fats. Higher concentrations of long-chain saturated fatty acids promote the formation of solid fat, resulting in a more stable fat crystal network and the development of fine, uniform ice crystals (Corradini et al., 2014; Chen et al., 2024). In fact, adjusting the balance between saturated and unsaturated fatty acids allows ice cream manufacturers to optimize formulations, improving stability during freezing and thawing processes, which is especially relevant in hot climates or during prolonged storage and transportation. Moreover, an increase in the proportion of long-chain fatty acids may enhance melt resistance, ensuring greater stability under fluctuating temperature conditions (Chen et al., 2025).

Table 3. Fatty acid profile of ice cream formulations with different proportions of GBB.

Ice cream formulations	Fatty acids								
	C8:0	C10:0	C12:0	C14:0	C16:0	C16:1 cis	C18:0	C18:1 n9c	C18:2 n6c
0%_GBB	1.31 ± 0.05 a	3.22 ± 0.25 a	40.11 ± 0.28 a	17.97 ± 0.10 a	11.64 ± 0.16 c	0.00±0.00	9.33 ± 0.23 ab	5.86 ± 0.15 c	1.00 ± 0.03 c
25%_GBB	1.34 ± 0.04 a	3.29 ± 0.21 a	38.84 ± 0.16 ab	17.61 ± 0.61 a	12.22 ± 0.11 b	0.00±0.00	10.20 ± 0.53 a	5.98 ± 0.36 c	0.90 ± 0.05 d
50%_GBB	0.87 ± 0.08 b	3.34 ± 0.11 a	38.31 ± 1.67 ab	18.66 ± 1.47 a	11.94 ± 0.20 bc	0.00±0.00	9.40 ± 0.33 ab	6.41 ± 0.11 bc	1.06 ± 0.01 bc
75%_GBB	0.89 ± 0.03 b	3.07 ± 0.17 a	37.65 ± 0.25 b	17.49 ± 0.21 a	12.99 ± 0.14 a	0.09 ± 0.01 a	9.96 ± 0.29 a	6.75 ± 0.15 ab	1.14 ± 0.02 ab
100%_GBB	0.65 ± 0.02 c	3.02 ± 0.17 a	38.19 ± 0.30 ab	18.28 ± 0.22 a	13.05 ± 0.13 a	0.17 ± 0.01 b	8.71 ± 0.06 b	7.22 ± 0.19 a	1.16 ± 0.02 a

Mean ± SD (n = 3). Different letters in the same column indicate statistically significant differences between formulations ($p \leq 0.05$), as determined by Tukey's test.

3.7. Microbiological analysis

The analyzed formulations met the microbiological quality standards established by Brazilian legislation for sensory analysis (Brasil, 2022b). *Salmonella* was absent in all samples, and coagulase-positive *Staphylococcus* and *Enterobacteriaceae* were not detected (Table 5). These results indicate that the ice cream formulations presented a satisfactory microbiological profile, complying with sanitary requirements and ensuring food safety for consumers. Proper control of these pathogens is essential for product acceptance in the market, ensuring that it is free of contaminants that may pose risks to public health (Adams, McClure, Moss; 2024).

Table 5. Microbial count in ice cream formulations with different proportions of GBB.

Treatments	<i>Salmonella</i> /25g	<i>Staphylococcus</i> coagulase positiva/g	<i>Enterobacteriaceae</i> /g
0%_GBB	Abs	<100 CFU/g	<10 CFU/g
25%_GBB	Abs	<100 CFU/g	<10 CFU/g
50%_GBB	Abs	<100 CFU/g	<10 CFU/g
75%_GBB	Abs	<100 CFU/g	<10 CFU/g
100%_GBB	Abs	<100 CFU/g	<10 CFU/g

Notes: Abs: absent in the tested sample; <100 CFU/g and <10 CFU/g: counts below the detection limit of the method used. CFU/g: Colony Forming Units per gram of sample.

3.8. Sensory analysis

While previous studies, such as those by Soares et al. (2024) e Cardoso et al. (2023), have applied consumer tests to evaluate GBB as a fat substitute in ice cream, the present study employed a multiple comparison test with semi-trained panelists. The focus was on assessing sensory attributes to determine the quality of ice cream containing GBB.

Sensory perception of ice cream relies on attributes like color, sweetness, flavor, creaminess, spoonability, and fatty mouthfeel, which are key indicators of quality and stability. Conversely, visible or textured ice crystals signal processing or storage flaws, reducing consumer appeal. Evaluating these factors helps refine formulations and processes, ensuring a more consistent and appealing product (Clarke 2012; Rolon et al., 2017)

The formulation with 25% GBB stood out with the highest ($p \leq 0.05$) average score, ranging from 4.71 to 5.38 compared to the other formulations with GBB addition. However, no difference ($p > 0.05$) against control sample (0% GBB) was observed (4.96 to 5.54) for all sensory attributes.

The results for color and sweetness were consistent with instrumental results, showing that higher concentrations of GBB resulted in increased color intensity and a decrease in perceived sweetness. Additionally, it was observed a decrease in perceived coconut flavor with higher GBB concentrations, except in the 25% formulation. Soares et al. (2024) also found that formulations with higher levels of GBB (30%) presented differences in color, texture, and flavor ($p \leq 0.05$) against to the control.

Regarding the ice crystals mouthfeel and fatty mouthfeel attributes, no differences were observed among the samples with different GBB concentrations, suggesting that GBB did not compromise ice cream quality of these attributes.

However, samples containing 75% and 100% GBB presented differences in creaminess compared to the standard formulation, while the other samples presented only minor variations.

This can be attributed to the thickening and gelling properties of GBB, which increase viscosity, solubility, and contribute to a creamier texture. Moreover, resistant starch in GBB may help minimize recrystallization, promoting a more homogeneous and stable ice cream structure during processing and storage (Amini Khoozani et al., 2019; Palanisamy and Parimalavalli, 2022).

Additionally, the three formulations with higher GBB content (50%, 75%, and 100%) exhibited lower spoonability ($p \leq 0.05$) compared to the standard ice cream, which correlates with the instrumental firmness results, as these formulations also presented higher values. This could indicate these formulations with higher GBB became firmer, making them more difficult to scoop. This finding aligns with Fuangpaiboon and Kijroongrojana (2017), who reported that ice creams made with carbohydrate-based fat replacers, such as GBB, tend to become more firmer, resulting in reduced spoonability compared to traditional formulations.

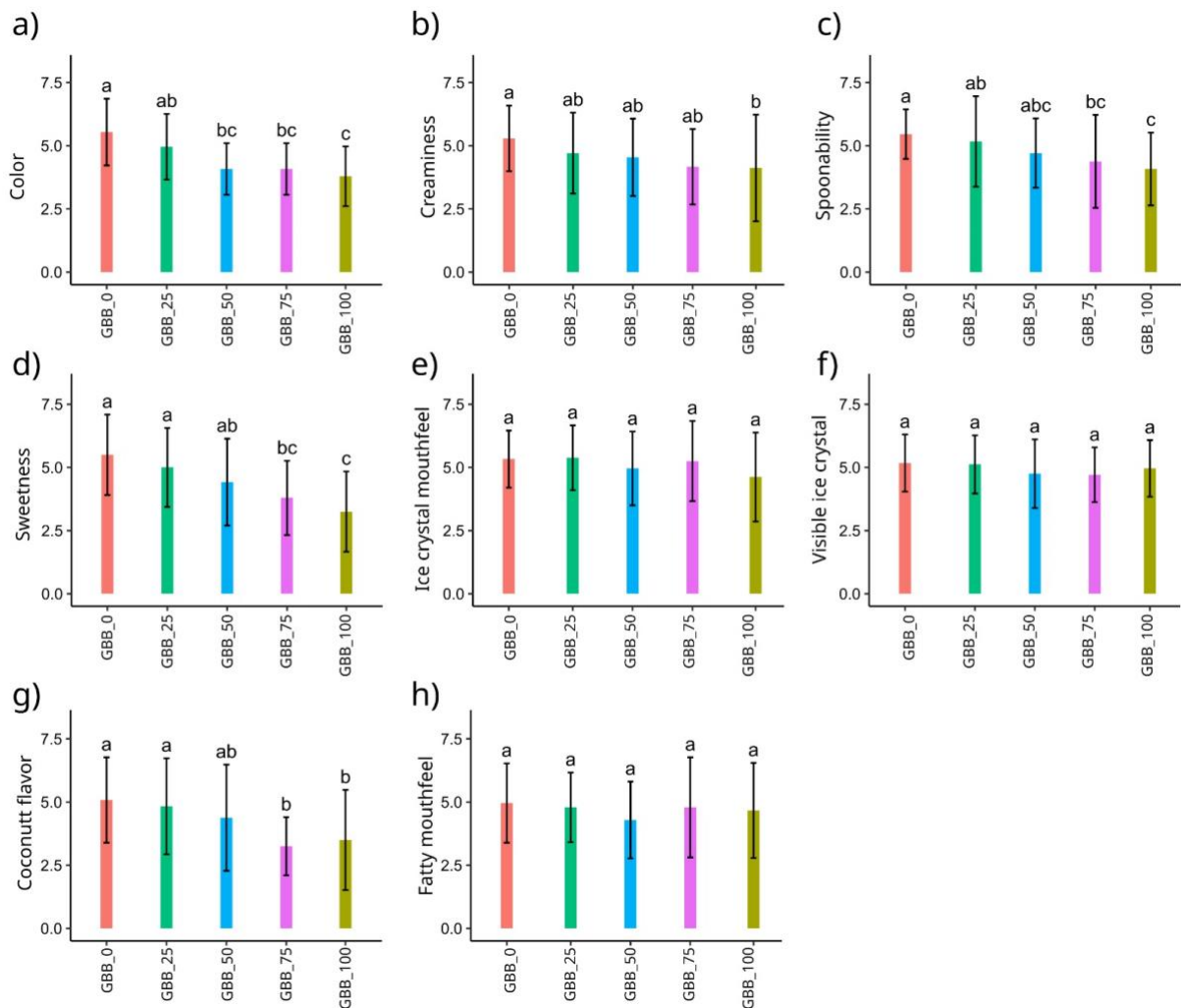


Fig. 4. Sensory profile of ice creams formulated with different proportions of green banana biomass as a fat replacer. The red line represents the standard formulation (0% biomass). Bars marked with * indicate statistically significant differences ($p \leq 0.05$) compared to the standard formulation.

3.9. Regression analysis

The mathematical modules revealed significant relationships between the independent variables and the physicochemical and sensory properties of the product (Table 5). The coefficients of determination ($R^2 > 0.99$) and statistical significance (p-value) of the models indicate that GBB has a good model adjustment.

The equations for soluble solids, pH, titratable acidity, overrun, and L^* showed a good fit ($R^2 \geq 0.986$), highlighting a direct and significant relationship between these responses and the GBB.

Only the firmness model fit a quadratic model, showing an interaction between heavy cream and GBB, with an R^2 value of 0.998. This demonstrated the effect of GBB on the ice cream structure, possibly due to the interaction of resistant starch present in the biomass with the proteins in the cream, modifying the viscosity and texture (Cardoso et al., 2023).

The sensory variables also showed good model adjustments with R^2 values above 0.99. Color, visual ice crystals, coconut flavor, sweetness, fatty mouthfeel, creaminess, ice crystal sensation in the mouth, and spoonability were influenced by the proportion of GBB. The linear models indicate that GBB significantly affects the sensory perception of the ice cream. As previously mentioned, the increase in biomass contributed to a more intense color, possibly due to greater water retention and modification of the product's sensory profile, due to its complex composition.

Mixture design is an approach within response surface methodology in which the final product results from the combination of different ingredients. The proportions of these components are defined by mathematical models, which may follow a linear, quadratic, or cubic structure (Ferreira et al., 2019).

Overall, the results indicate that GBB has a significant impact on the physicochemical and sensory properties of ice cream. The strong predictive power of the models ($R^2 \geq 0.99$ for most variables) demonstrates that the variables can be efficiently controlled by adjusting the proportion of heavy cream and GBB. The biomass not only replaces fat but also contributes to improvements in creaminess, stability, and sensory perception of the ice cream, making it a viable alternative for developing healthier and more sustainable products.

Table 5. Mathematical models and determination coefficients (R^2) for the different response variables of ice cream formulations with varying proportions of green banana biomass.

Responses	Regression equation	<i>R Square</i>	<i>p-value</i>
Soluble Solids	$30.95X_1 + 27.73X_2$	0.99983	< 0.0001
pH	$6.92X_1 + 6.82X_2$	0.99991	< 0.0001
Titrateable acidity	$0.25X_1 + 0.28X_2$	0.98628	0.00075
Overrun	$31.32X_1 + 18.17X_2$	0.99292	0.00028
Firmness	$16.09X_1 + 48.39X_2 + 106.59X_1X_2$	0.99827	0.00104
L*	$92.11X_1 + 85.78X_2$	0.99998	< 0.0001
Sensory parameters			
Color	$5.37X_1 + 3.61X_2$	0.99626	0.00011
Ice crystals (visual)	$5.42X_1 + 4.79X_2$	0.99792	< 0.0001
Coconut flavor	$5.16X_1 + 3.26X_2$	0.99362	0.00024
Sweetness	$5.53X_1 + 3.25X_2$	0.99993	< 0.0001
Fatty mouthfeel	$4.82X_1 + 4.58X_2$	0.99670	< 0.0001
Creaminess	$5.14X_1 + 3.99X_2$	0.99886	< 0.0001
Ice crystals mouthfeel	$5.11X_1 + 4.77X_2$	0.99856	< 0.0001
Spoonability	$5.47X_1 + 4.05X_2$	0.99990	< 0.0001

Notes: X_1 : percentage of heavy cream; X_2 : percentage of green banana biomass. R Square: coefficient of determination. p-value: statistical significance of the regression model (values < 0.05 indicate significant models). L*: luminosity.

4. CONCLUSION

This study demonstrated that green banana biomass (GBB) can partially replace fat in ice cream, offering nutritional benefits through the reduction of saturated fatty acids. The replacement of up to 25% of heavy cream with GBB maintained sensory characteristics similar to the control (0% GBB), while higher levels of biomass led to perceptible changes in flavor and texture. The addition of GBB delayed ice cream melting due to its water-holding capacity and thickening properties, in addition to improving creaminess and reducing the ice crystals mouthfeel. These results indicate that GBB is a functional and sustainable alternative, utilizing a by-product of green bananas to produce ice cream with improved stability and nutritional value. These findings may guide the food industry in developing healthier products aligned with the growing consumer demand for plant-based and sustainable options.

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CONCLUSÕES E RECOMENDAÇÕES DE PESQUISA

Os estudos conduzidos nesta dissertação permitiram reunir conhecimentos teóricos e práticos sobre a aplicação de substitutos de gordura à base de amido, com foco na biomassa de banana verde (BBV), no desenvolvimento de sorvetes mais saudáveis. O Capítulo I, por meio de uma revisão abrangente da literatura, foi fundamental para orientar o desenvolvimento experimental do Capítulo II, uma vez que proporcionou uma compreensão aprofundada dos mecanismos, propriedades e desafios associados ao uso de miméticos de gordura à base de amido em sorvetes. A revisão destacou que diversos tipos de amido, particularmente o amido resistente presente na BBV, possuem grande potencial para substituir a gordura, mantendo características sensoriais e tecnológicas desejáveis.

Com base nessas evidências teóricas, o Capítulo II aplicou esses conhecimentos na formulação de sorvete de coco com diferentes níveis de substituição de creme de leite por BBV. Os resultados demonstraram que a substituição de até 25% do creme por BBV é tecnicamente viável, mantendo a aceitação sensorial, aparência, textura e sabor semelhantes à formulação controle. Além disso, a BBV conferiu benefícios tecnológicos, como a redução da taxa de derretimento, e benefícios nutricionais, como a redução de ácidos graxos saturados. Por outro lado, níveis de substituição mais altos (acima de 50%) comprometeram as características sensoriais e físico-químicas do sorvete, evidenciando a importância de se encontrar um equilíbrio entre funcionalidade tecnológica e aceitação.

Assim, esse estudo não apenas confirma o potencial da BBV como substituto de gordura em sorvetes, mas também contribui para a diversificação de ingredientes funcionais derivados de subprodutos agrícolas, promovendo inovação e saudabilidade no setor alimentício.

Recomenda-se que pesquisas futuras explorem a combinação da BBV com outros ingredientes, como proteínas ou hidrocoloides, para melhorar a textura e qualidade sensorial em maiores níveis de substituição de gordura, avaliem sua aplicação em formulações *100% plant-based*, além de avaliar a vida útil e estabilidade durante o armazenamento, considerando que gere impacto nas características físico-químicas, em particular a microestrutura do sorvete ao longo do tempo.