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Application of Annealed Bambara Starch as a Stabilizer in Ice Cream Production

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Abstract: This study investigated the potential of annealed Bambara starch as a locally sourced stabilizer for ice cream, aimed at addressing the high cost of imported stabilizers. Annealed Bambara starch, modified at various temperatures (45, 50, 55, and 60 °C), was incorporated into ice cream formulations and compared with ice cream stabilized using xanthan gum and guar gum. The ice creams exhibited variations in percentage overrun (77.03–124.61%), foam stability (90.88–96.61%), viscosity (24.87–33.26%), and melting resistance. Conventionally stabilized ice cream outperformed in overrun, foam stability, viscosity, and melting rate properties. Descriptive sensory tests showed high intensity scores for color, aroma, taste, mouthfeel, and body attributes across all samples, with no weak intensity scores. Considering the performance of conventionally stabilized ice cream, those stabilized with Bambara starch annealed at 45 and 50 °C were recommended as potential alternatives, highlighting the potential of annealed Bambara starch as a cost-effective and locally sourced stabilizer for ice cream. Further studies should investigate the impact of annealing at different temperatures on the structural changes of Bambara starch to gain more insights into its effects on ice cream structure, facilitating its use in other food systems.

Keywords: annealing; Bambara starch; stabilizers; ice cream; sensory characteristics

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Citation: Nwaogazie, F.O.; Akinwande, B.A.; Adebo, O.A.; Oyeyinka, S.A. Application of Annealed Bambara Starch as a Stabilizer in Ice Cream Production. *Macromol* **2024**, *4*, 533–543. https://doi.org/10.3390/macromol4030031

Academic Editor: Luis Alves

Received: 11 June 2024
Revised: 10 July 2024
Accepted: 14 July 2024
Published: 25 July 2024

1. Introduction

Bambara groundnut (*Vigna subterranea* (L.) verdc) is a neglected legume of African origin [1] that is gradually gaining relevance due to its relatively high nutritional composition and ability to withstand drought [2] and hot climates [3]. It is rich in protein (15–27%) and carbohydrates (57–67%) including starch [4]. The starch of Bambara grain may vary between 18 and 45% and may have food and pharmaceutical applications [5–8]. Currently, corn, potato, and cassava are the major sources of starch for industrial use. However, the growing demand for starch by the industry has increased the search for alternative sources of starch such as those extracted from pulses including Bambara groundnut. The increased interest in pulse starches has been associated with their high amylose and high content of resistant starch [9]. However, starch in its native form is not suited for most industrial applications [10], due to their inherent limitations such as high retrogradation and poor resistance to high temperatures frequently encountered during processing [4]. Therefore, starches are modified to improve functionality and applications in the industry [11]. Starches undergo diverse modifications aimed at enhancing their functionality and expanding their applications across different industries. These modifications include physical, chemical, and enzymatic treatments that alter starch properties such as viscosity, gelation, retrogradation behavior, and thermal stability. By tailoring starches to specific needs, such as improving binding properties in food processing, or providing stability in industrial applications, modified starches play a crucial role in meeting technological demands and consumer preferences. In general, starch modification may be achieved by physical, enzymatic, genetic, and chemical methods or a combination of these methods. Of these methods, physical methods such as annealing are gaining more interest and acceptability, because they are safe, environmentally friendly, inexpensive, and simple to use compared to chemical methods [10,12].

Starch modification by annealing involves the heating of a starch–water mixture, usually in ratios of one to two, respectively, for varying times. The resulting annealed starch is reported to show improved thermal stability and a decreased rate of retrogradation [13]. Previous studies on the annealing of Bambara starch found significant reductions in peak, breakdown, and setback viscosities but an increase in final viscosity and pasting temperature [12,14–16]. Furthermore, in our previous study, we reported that an increase in annealing temperatures significantly reduced paste clarity, gelatinization temperature, peak viscosity, trough, final viscosity, and the peak time of Bambara starches [12]. The reduction in these parameters is thought to result from a decrease in the extent of hydration of starch crystalline by strengthening the interaction of starch chains and stabilizing the double helix structure within the starch granules [17]. This behavior suggests the suitability of annealed starches in enhancing the stability of frozen foods such as ice cream.

Ice cream is a frozen, sweetened dairy product, loved and consumed by people around the globe [18]. It is a complex food product made up of an emulsion, foam, gel, and suspension [19]. The removal of one ingredient may negatively affect the stability and sensory characteristics of the product, rendering it unacceptable to consumers. Hence, stabilizers such as polysaccharide gums are used in ice cream production to enhance viscosity and prevent a collapse of the mix. Although conventional stabilizers have been utilized by manufacturers and researchers to improve the mouthfeel and stability of ice creams [20], in recent times, the use of cheaper and safer alternatives such as conventional gums and modified starch has continued to increase [21–23]. Earlier studies suggested the use of modified starches as fat replacers or stabilizers in ice cream production [19,24,25]. Sweet potato-modified starch treated with citric acid reportedly produced reduced-fat ice creams with physicochemical and sensory characteristics similar to those with normal fat [25]. The use of Bambara starch modified through annealing may serve as an alternative stabilizing agent for ice cream production since the annealed starch has been shown to inhibit freeze-thawing compared to native starch [12]. Therefore, this study investigated the potential of annealed Bambara starch for use as a stabilizer in ice cream.

2. Materials and Methods

2.1. Materials

Bambara groundnut with cream seed coat used for starch extraction and other ingredients such as milk fat, milk solids non-fat (skimmed milk powder), sugar, and flavoring used during ice cream production were procured from a local market in Ibadan, Oyo State, Nigeria. Laboratory analyses were performed at the National Horticultural Research Institute and the Central Research Laboratory, University of Ibadan, Oyo State, Nigeria.

2.2. Extraction and Annealing of Bambara Starch

Bambara starch was extracted and annealed as described by Nwaogazie et al. [12]. For starch extraction, cleaned grains were soaked in water for 14 h to soften the granules. The grains were dehulled, milled, and sieved using a muslin cloth. The residue obtained after sieving was discarded, and the filtrate containing the starch was allowed to settle for 12 h. The sedimented starch was dissolved in 0.3% (w/v) NaOH to remove residual proteins, and the slurry was continually washed with water until the starch tested negative for the presence of protein. The starch slurry was neutralized with HCl (0.1 N) and washed several times with distilled water. The extracted starch was dried in an oven at 50 °C for 10 h, milled, and sieved using a sieve with an aperture size of 180 μm. The dried starch was packaged in Ziplock bags and stored at 4 °C until needed for ice cream production.

The annealing process involved placing starch (125 g) in a foil-sealed beaker suspended in distilled water (1:2 *w*/*v*) and heated for 24 h in a sealed container placed in a water bath. Four different annealing temperatures of 45, 50, 55, and 60 °C were used, as we previously reported [12]. The suspensions obtained were filtered using Whatman No. 1 filter paper and subsequently oven-dried at 50 °C for 12 h in an INESA DHG-9123 oven. The dried, annealed starches were then ground with and sieved through a 180 µm aperture sieve. Finally, the processed starches were packaged in Ziplock bags for further analysis.

2.3. Ice Cream Mix Formulation and Production

Ice cream was produced according to the method of Wang [26] with a slight modification. An amount of 0.25 g of Bambara starch annealed at 45, 50, 55, and 60 °C was incorporated in 400 g ice cream formulated mixes in plastic transparent plates to function as a stabilizer. A conventional ice cream which served as the control (standard) was produced in triplicate and stabilized using both xanthan gum and guar gum (0.25 g: 0.125 g). The ice cream mix contained 200 mL distilled water, 86.5 g milk fat, 60 g milk solids non-fat (skimmed milk powder), 52.75 g sugar, and 0.5 mL vanilla flavor. Milk fat, non-fat solids, stabilizers, and sweeteners were combined in a saucepan and thoroughly mixed to ensure complete integration of both liquid and dry ingredients. The ice cream mixture was then pasteurized at 68.3 °C for 30 min. Following pasteurization, the mixture was homogenized at pressures between 2500 and 3000 psi to reduce the size of the milk fat globules, create a more stable emulsion, and produce a smoother, creamier texture.

The ice cream mix was then aged at 40 °F (5 °C) for 4 h to cool it down before freezing, allow the milk fat to partially crystallize, give the protein stabilizers time to hydrate, and improve the whipping properties of the mix. The liquid vanilla flavor was then added to the mix and blending of the whole mix took place before freezing. Thereafter, freezing took place for 15 min, which involved freezing the mix and incorporating air in a batch freezer. Hardening then commenced, and thus, the ice cream was cooled as quickly as possible down to a holding temperature of less than 13 °F (−10.5 °C). The ice creams were then packaged in labeled plastic containers pending sensory evaluation and analyses.

2.4. Percentage Overrun

The ice cream's percentage overrun was assessed following a modified version of the method described by Otutu et al. [27]. Thirty grams of ice cream mix was whipped for 5 min using a domestic mixer (Kenwood HM 430, Shanghai, China). The weight of the mix was recorded before and after freezing. The overrun, indicating the percentage of air incorporated into the product, was calculated using the following formula: $(W_2 - W_1)/W_1$, where W_2 represents the weight of the mix before freezing and W_1 represents the weight after freezing.

2.5. Foam Stability

The foam stability was evaluated using a modified method of Alakali et al. [28]. Two hundred milliliters of the ice cream mix were whipped in a domestic mixer (Marlex Excella model, Kanchan International Limited, Daman, India) for 15 min at a turbo speed setting (planetary rpm of 220 and beaters rpm of 730) to create foam. The whipping was conducted at room temperature (23 ± 2 °C). The resulting foamed mix was then transferred into a graduated cylinder (250 mL), and the total volume of foam was measured as V_1. After 5 s, the final volume of the foam (V_2), was recorded. The percentage foam stability was calculated using the following formula: $[(V_1 - V_2)/V_1] \times 100$.

2.6. Viscosity

The viscosity of the ice cream mix was determined using the method of Thaiudom et al. [22] with a slight modification. It was measured using a Brookfield Metek (Dv-1) Viscometer. Each sample was poured into a 250 mL beaker and mixed adequately with a spatula. An amount of 70 mL of each sample was then poured into a transparent small cylinder container and placed underneath the viscometer. The viscometer was set, and the viscosity of the samples was measured in triplicates.

2.7. Meltdown Rate

The ice cream meltdown was assessed using a modified method reported by Singo and Beswa [29] with a slight modification. The ice cream sample (80 g) was placed on a wire mesh positioned above a graduated glass cylinder on a weighing balance, maintained at a controlled temperature of 25 ± 1 °C. The volume of melted ice cream was measured at 5 min intervals over 45 min. The initial drop time was recorded as the volume drip per minute. The data collected were then used to determine the meltdown rate, expressed in grams per minute.

2.8. Sensory Evaluation

Sensory evaluation of the ice creams was performed using a descriptive test (quantitative descriptive analysis) to analyze and quantify the sensory attributes of the products [30]. The ice creams were assessed for creaminess, aroma, sweetness, smoothness, and firmness. A prescreening and a rigorous training session were conducted before the actual product sensory evaluation. Twelve trained panelists (7 females and 5 males) from the Department of Food Technology, University of Ibadan evaluated the coded samples, which are the annealed stabilized ice creams and the conventionally stabilized ice cream (the reference) after 24 h of refrigeration. This conventional ice cream stabilized with xanthan and guar gum exemplified the desired characteristics a good ice cream should possess. The panelists evaluated one sample at a time in triplicates and indicated their findings on a 15 cm anchored line scale whose endpoints showed the attributes' degree of intensity, and this evaluation took place in a standard sensory boot with white lights. Panelists rinsed their mouths with cold water between samples. The panelists rated the intensity of each attribute by marking a vertical mark across the appropriate horizontal rating line on the scorecard. These marks were converted to numerical data by measuring the distance from the origin ("weak") to the vertical mark. The data obtained were used to determine if the annealed stabilized ice creams can be comparable to the conventionally stabilized ones. The scorecard had a 15 cm intensity line scale. Values of 0–5 represented weak, 6–10 represented not too strong, while 11–15 represented very strong. The ranges of ice cream characteristics identified are described in Table 1 below.

Table 1. Sensory descriptors for Bambara starch-stabilized ice cream.

Sensory Descriptors	Range of Sensory Descriptors
Color	Off-white, white, and cream
Aroma	Plain, mild, and intense
Mouthfeel	Gritty, slightly smooth, and smooth
Body	Unstable, slightly firm, and very firm
Taste	Bland, slightly sweet, and very sweet

2.9. Statistical Analysis

Samples were prepared in triplicate and analyses were performed in duplicates. Additionally, data obtained were analyzed using the Statistical Package for Social Sciences, Version 21 (SPSS Inc., Chicago, IL, USA). Statistical significance was evaluated through analysis of variance (ANOVA), with Duncan's test applied to distinguish the means. Differences were considered significant at a 95% confidence level ($p < 0.05$). Pearson correlation was employed to determine the relationships between selected parameters, with significance expressed at a 10% confidence level ($p < 0.01$).

3. Results and Discussion

3.1. Effect of Annealed Bambara Starch on Overrun of Ice Creams

The overrun of ice creams was significantly ($p < 0.05$) affected by the addition of annealed Bambara starch (Figure 1). Overrun values which represent the increase in ice cream volume during cold whip ranged between 77.03 and 124.61% for ice cream stabilized with Bambara starch annealed at 60 °C and the control, respectively. These values decreased with increasing annealing temperatures (45 °C > 50 °C > 55 °C > 60 °C). Ice cream stabilized with Bambara starch annealed at 45 °C showed comparable overrun values to the control. Overrun is reported to be influenced by fat content, solids, sweeteners, and the presence of stabilizing materials [31]. In an earlier study, we investigated the impact of different annealing temperatures (45, 50, 55, and 60 °C) on the physicochemical properties of Bambara starch and found that starch annealed at 45 °C displayed higher viscosity and better freeze–thaw stability than starches annealed at higher temperatures [12]. Thus, the higher overrun values of ice cream stabilized with Bambara starch annealed at 45 °C may be explained by its higher viscosity values. Earlier researchers reported that the viscosity of stabilizing agents is an important factor that affects the overrun of ice cream [32–34]. Higher viscosity likely results in ice cream with better consistency because it slows down the movement of particles [32–34]. A higher overrun percentage results in softer ice cream and increased profitability. The overrun observed in this study is comparable to the values reported for ice cream stabilized with acetylated cassava starch [27] and crosslinked cassava starch [19].

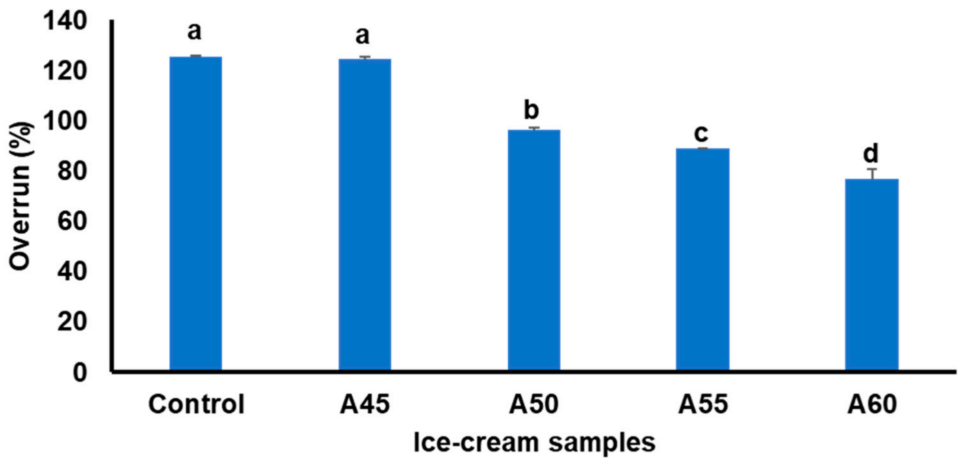

Figure 1. Ice creams' overrun percentage. Control: conventional stabilized ice cream, A45: ice cream stabilized by starch annealed at 45 °C, A50: ice cream stabilized by starch annealed at 50 °C, A55: ice cream stabilized by starch annealed at 55 °C, A60: ice cream stabilized by starch annealed at 60 °C. The letters denote different levels of statistical significance ($p < 0.05$). Bars with the same letters indicate no significant differences between the samples.

3.2. Effect of Annealed Bambara Starch on Foam Stability of Ice Creams

The stability of the whipped foams in the different ice cream mixes varied between 90.88 and 97.99% (Figure 2). All the ice creams containing annealed Bambara starch showed significantly ($p < 0.05$) lower foam stability compared to the control sample containing guar and xanthan gums, indicating that the latter was the most stable. In general, a slower foam collapse is a desired quality parameter of ice cream. The variation in foam stability across the ice cream types may be associated with differences in particle size as well as how homogeneously these particles are distributed [35]. Furthermore, it has been suggested that highly viscous stabilizers may enhance the stability of foams by limiting the movement of air bubbles in the mixes [22]. According to these authors [22], ice cream mixes containing less viscous stabilizers could not trap more air bubbles compared with highly viscous types, resulting in greater movement and collision of the bubbles. This mechanism presumably reduced the stability of the foams.

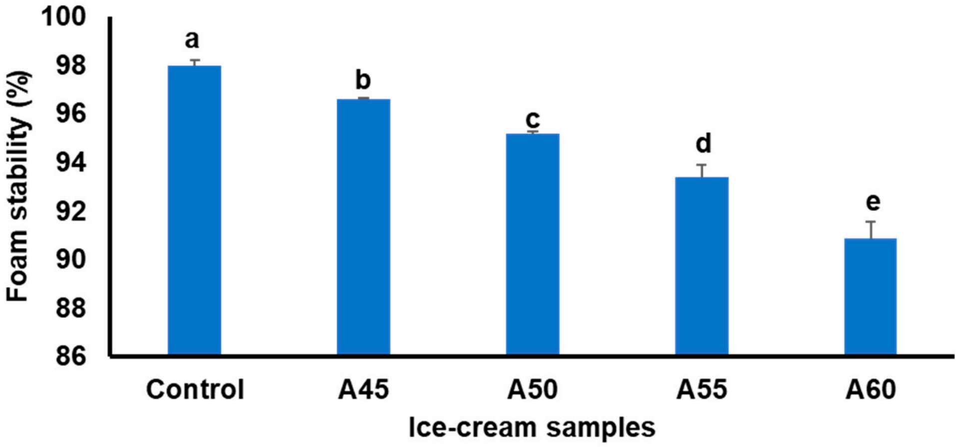

Figure 2. Foam stability of ice creams. Control: conventional stabilized ice cream, A45: ice cream stabilized by starch annealed at 45 °C, A50: ice cream stabilized by starch annealed at 50 °C, A55: ice cream stabilized by starch annealed at 55 °C, A60: ice cream stabilized by starch annealed at 60 °C. The letters denote different levels of statistical significance ($p < 0.05$). Bars with the same letters indicate no significant differences between the samples.

3.3. Effect of Annealed Bambara Starch on Viscosity of Ice Creams

The viscosity values (24.87–33.36 cP) of the ice cream stabilized with annealed Bambara starch were generally lower than that of the control which showed a value of 33.80 cP, though ice cream stabilized with Bambara starch annealed at 45 °C was similar to the control (Figure 3). Viscosity of ice cream is an important functional property that determines the quality and acceptability. An earlier study suggested that the increase in the viscosity of ice cream is thought to result from a combination of physicochemical changes including aggregation of fat globules especially during aging [36]. Furthermore, differences in the molecular weight of food components may also explain the variation in the viscosity of the ice cream [37]. In our previous report on the impact of annealing temperatures on physiochemical properties of Bambara starch, we associated the possibility of changes in molecular structure of amylopectin within the Bambara starch granule to the variation in viscosity [12]. In general, starch with higher proportions of long amylopectin chains would display higher viscosity. Thus, we hypothesize that the higher annealing temperatures (50, 55, and 60 °C) produced Bambara starch with fewer proportions of long amylopectin chains and more of short amylopectin chains. This suggests that changes in molecular weight of the starch after annealing treatment played a significant role in the viscosity of the ice cream. While our study did not examine the chain length distribution of amylopectin in Bambara starch, Su et al. [38] noted that annealing altered the distribution, increasing the proportion of shorter chains [A (DP 6–12) and B1 (DP 13–24)] compared to longer chains [B2 (DP 25–36) and B3 (DP > 37)]. The viscosity values in this study are in agreement with values previous reported for ice cream in the literature [39]. However, much higher values have also been reported by other authors [19,40,41]. Differences in viscosity of ice cream have been associated with the shear rate as well as the type and concentration of the stabilizer used [19,41]. Other factors such the method of incorporating stabilizers, the temperature during incorporation, the timing of stabilizer contact with the mixture, and solids and protein content can also influence the viscosity of ice cream [41].

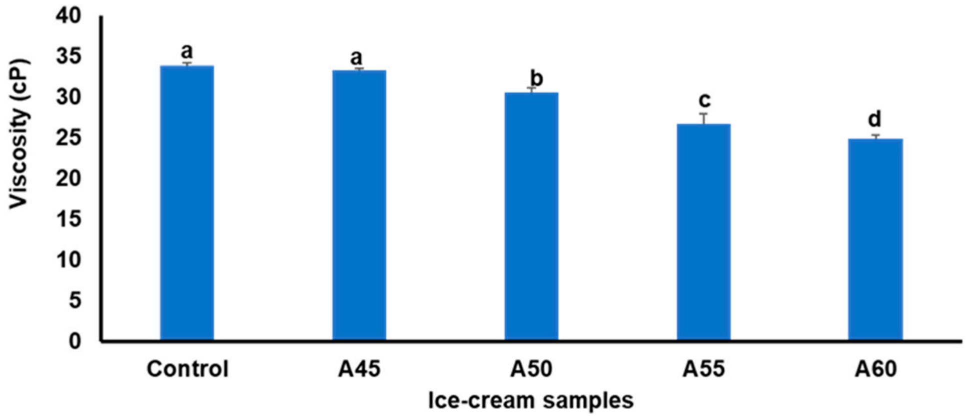

Figure 3. Viscosity of ice creams. Control: conventional stabilized ice cream, A45: ice cream stabilized by starch annealed at 45 °C, A50: ice cream stabilized by starch annealed at 50 °C, A55: ice cream stabilized by starch annealed at 55 °C, A60: ice cream annealed at 60 °C. The letters denote different levels of statistical significance ($p < 0.05$). Bars with the same letters indicate no significant differences between the samples.

3.4. Effect of Annealed Bambara Starch on Meltdown Rate of Ice Creams

The meltdown rate of the ice creams was conducted across various time frames (5, 10, 15, 20, 25, 30, 35, 40, and 45 min). The control ice cream stabilized with xanthan and guar gum had the lowest meltdown rate values, indicating a higher melting resistance (Table 2). The meltdown rate refers to how quickly the ice cream melts or transitions from a solid to a liquid state. A higher meltdown rate means the ice cream melts faster. On the other hand, meltdown resistance is indicative of how well the ice cream resists melting or maintains its structure before melting significantly. A higher meltdown resistance indicates that the ice cream melts more slowly. Among the ice creams stabilized with annealed Bambara starch, melting resistance decreased with annealing temperatures. The meltdown rate is one of the most important properties of ice cream that is influenced by its composition and fat globule size [42]. Stabilizer type, concentration, ice crystal content, as well as emulsifier level and type may also affect the meltdown rate of ice cream [43]. Lin et al. [44] also reported significant reductions in ice cream melting rate following the replacement of fat with chestnut, corn, and potato starch nanocrystals. According to these authors, the reduction in meltdown rate may be associated with the formation of a three-dimensional network by the starches. This structure presumably impedes the rate of heat transfer within the ice cream. Furthermore, starches with high-freeze–thaw stability have the potential to maintain the structural integrity of ice cream against water-induced damage [44,45]. In an earlier study, we found that Bambara starch annealed at 45 °C showed significantly higher freeze–thaw stability and lower setback viscosity than the counterparts annealed at higher temperatures (50–60 °C) [12]. Thus, it is probable that the structural modification of annealed starch helps to maintain the integrity of the ice cream structure. We hypothesize that annealing at lower temperatures did not significantly change the granular size of the starches compared to annealing at higher temperatures. Consequently, the relatively smaller starch granules can disperse more uniformly throughout the ice cream mixture, potentially leading to a more consistent thickening effect. This can result in a smoother texture and potentially slower melting due to the uniform structure. In contrast, larger starch granules may not disperse as evenly, which could create areas with varying viscosities, leading to an uneven melting rate within the ice cream structure. Annealing can lead to a more organized and stable crystalline structure within the starch granules, which enhances the formation of a 3D network. This network is more efficient at entrapping water, fats, and air, thereby improving the viscosity and stability of the ice cream mix. Further studies are required to understand the structural changes such as morphology, crystallinity pattern, chain length distribution of amylopectin, and secondary structure properties of the annealed starch to fully comprehend the impact of these changes on the ice cream structure. This may also provide insight into future applications of the modified starches in other food systems.

Table 2. Meltdown rate of annealed Bambara starch-stabilized ice creams (g/min).

Melting Time (min)	Control	A45	A50	A55	A60
5	1.90 ± 0.00 [a]	1.89 ± 0.00 [a]	1.77 ± 0.00 [b]	1.55 ± 0.00 [c]	1.53 ± 0.03 [c]
10	3.72 ± 0.00 [a]	3.70 ± 0.00 [b]	2.44 ± 0.00 [c]	2.24 ± 0.00 [d]	2.24 ± 0.00 [d]
15	4.05 ± 0.00 [a]	3.99 ± 0.00 [b]	3.64 ± 0.00 [c]	2.41 ± 0.00 [d]	2.40 ± 0.00 [e]
20	4.09 ± 0.00 [a]	4.08 ± 0.00 [b]	4.07 ± 0.00 [c]	3.63 ± 0.00 [d]	2.39 ± 0.00 [e]
25	4.32 ± 0.00 [a]	4.31 ± 0.00 [b]	4.29 ± 0.00 [c]	3.14 ± 0.00 [d]	2.34 ± 0.00 [e]
30	4.56 ± 0.00 [a]	4.55 ± 0.00 [b]	4.32 ± 0.00 [c]	3.23 ± 0.00 [d]	2.28 ± 0.00 [e]
35	4.62 ± 0.00 [a]	4.59 ± 0.00 [b]	4.38 ± 0.00 [c]	3.19 ± 0.00 [d]	2.19 ± 0.00 [e]
40	4.65 ± 0.00 [a]	4.65 ± 0.00 [a]	4.65 ± 0.00 [a]	3.08 ± 0.00 [b]	2.08 ± 0.06 [c]
45	4.67 ± 0.00 [a]	4.65 ± 0.00 [b]	4.51 ± 0.00 [c]	3.00 ± 0.00 [d]	2.08 ± 0.00 [e]

Means in the same row not followed by the same superscripts are significantly different ($p < 0.05$). Control: conventional stabilized ice cream, A45: ice cream stabilized by starch annealed at 45 °C, A50: ice cream stabilized by starch annealed at 50 °C, A55: ice cream stabilized by starch annealed at 55 °C, A60: ice cream stabilized by starch annealed at 60 °C.

3.5. Sensory Characteristics of Annealed Bambara Starch-Stabilized Ice Creams

The values of sensory characteristics of the ice creams are presented in Table 3.

Table 3. Mean sensory scores for Bambara starch-stabilized ice cream.

Samples	Taste	Aroma	Mouthfeel	Body	Color
CSI 101	13.32 ± 0.29 [a]	14.65 ± 0.13 [a]	14.92 ± 0.12 [a]	14.98 ± 0.04 [a]	13.78 ± 0.21 [a]
ASI 201	13.30 ± 0.29 [a]	14.55 ± 0.21 [ab]	14.31 ± 0.21 [b]	14.28 ± 0.24 [b]	13.67 ±0.19 [ab]
ASI 202	13.21 ± 0.22 [a]	14.28 ± 0.24 [bc]	12.23 ± 0.44 [c]	11.93 ± 0.12 [c]	13.58 ± 0.31 [b]
AS1 203	13.33 ± 0.26 [a]	14.43 ± 0.17 [c]	8.87 ± 0.41 [d]	8.41 ± 0.22 [d]	13.38 ± 0.16 [c]
ASI 204	13.13 ± 0.23 [a]	14.08 ± 0.16 [d]	7.50 ± 0.49 [e]	6.73 ± 0.37 [e]	12.98 ± 0.06 [d]

Means in the same column not followed by the same superscripts are significantly different. There were significant differences in the sensory properties of the annealed stabilized ice creams. All values were means of triplicate determination of twelve panelists. CSI 101 (conventional stabilized ice cream), ASI 201 (45 °C annealed stabilized ice cream), ASI 202 (50 °C annealed stabilized ice cream), ASI 203 (55 °C annealed stabilized ice cream), ASI 204 (60 °C annealed stabilized ice cream). The scorecard values line scale ranges from 0 to 5 (weak), 6 to 10 (strong), and 11 to 15 (very strong).

Except for taste, which was similar across samples, there were significant differences ($p < 0.05$) in the sensory characteristics of the ice cream samples. This suggests that the annealed starches compared favorably with the taste of the control sample. Furthermore, except for the mouthfeel and body of the ice cream samples stabilized with Bambara starch annealed at 55 °C and 60 °C, which showed scores (6.73–8.87) lower than the range for very strong (11–15), all the ice cream samples showed very strong attributes for taste, aroma, and color. The results of the sensory properties indicate that annealed Bambara starch did not substantially change the characteristics of the ice cream.

3.6. Pearson Correlation

The Pearson correlation among the measured functional properties (meltdown rate, foam stability, overrun, and viscosity) are presented in Table 4. All the meltdown rates showed a significant positive ($p < 0.01$) correlation with foam stability ($0.857 \leq r \leq 0.951$), overrun ($0.774 \leq r \leq 0.945$), and viscosity ($0.837 \leq r \leq 0.976$). Previous studies also found a positive correlation between the melting rate of ice cream with its viscosity, with a higher viscosity resulting in superior resistance to melting [44,46]. In this study, the viscosity (33.26 cP) of ice cream stabilized with annealed Bambara starch was similar to that of the control (33.80 cP) (Figure 3), which may explain the closeness in their melting rate properties. Similarly, the foam stability positively correlated significantly with viscosity (r = 0.963, $p < 0.01$) and overrun (r = 0.948, $p < 0.01$). A significant positive correlation was also observed between viscosity and overrun (r = 0.951, $p < 0.01$). This indicates that higher viscosity facilitates better air incorporation and stabilizes air bubbles, leading to higher overrun and a lighter texture, enhancing overall stability.

Table 4. Pearson correlation matrix for meltdown rate, foam stability, viscosity, and overrun of ice creams stabilized with annealed Bambara starch.

	5 min	10 min	15 min	20 min	25 min	30 min	35 min	40 min	45 min	FS (%)	Viscosity (cP)	Overrun (%)
5 min	1											
10 min	0.902 **	1										
15 min	0.992 **	0.855 **	1									
20 min	0.787 **	0.601 *	0.788 **	1								
25 min	0.923 **	0.718 **	0.937 **	0.946 **	1							
30 min	0.935 **	0.762 **	0.941 **	0.950 **	0.997 **	1						
35 min	0.935 **	0.758 **	0.940 **	0.950 **	0.997 **	1.000 **	1					
40 min	0.925 **	0.713 **	0.940 **	0.940 **	1.000 **	0.995 **	0.995 **	1				
45 min	0.943 **	0.751 **	0.954 **	0.932 **	0.999 **	0.997 **	0.998 **	0.998 **	1			
FS (%)	0.938 **	0.857 **	0.916 **	0.889 **	0.931 **	0.952 **	0.951 **	0.927 **	0.939 **	1		
Viscosity (cP)	0.976 **	0.895 **	0.968 **	0.837 **	0.934 **	0.951 **	0.949 **	0.931 **	0.949 **	0.963 **	1	
Overrun (%)	0.945 **	0.968 **	0.905 **	0.774 **	0.847 **	0.883 **	0.880 **	0.841 **	0.868 **	0.948 **	0.951 **	1

Means in the same row not followed by the same superscripts are significantly different ($p < 0.05$). FS: Foam stability. The time in minutes represents the meltdown rate, ** = significant correlations at 10% (0.01) and * = significant correlations at 5% (0.05).

4. Conclusions

The results of this study revealed no significant difference in the overrun and viscosity of ice creams stabilized with Bambara starch annealed at 45 °C compared to those stabilized with commercial gums (xanthan and guar gum). Conventional stabilizers provided the highest foam stability, likely due to their higher viscosities, which typically contribute to better foam stability. However, ice cream stabilized with Bambara starch annealed at 45 °C had a foam stability value almost similar to the control. While xanthan and guar gum-stabilized ice creams exhibited the highest melting resistance, the melting resistance of ice creams stabilized with Bambara starch annealed at 45 and 50 °C was nearly comparable. There were no significant differences in the descriptive sensory properties of ice creams stabilized with Bambara starch annealed at 45 and 50 °C compared to those stabilized with xanthan and guar gum. This research suggests that annealed Bambara starch has potential as a stabilizer in ice cream production, particularly at 45 °C, and could be used alone or in blends. Further research is recommended to explore the use of annealed Bambara starch as a stabilizer in other dairy products and to investigate other physical modification methods for Bambara starch for potential applications in ice cream.

Author Contributions: Conceptualization, B.A.A. and F.O.N.; methodology, B.A.A., F.O.N. and S.A.O.; validation, B.A.A., O.A.A. and S.A.O.; formal analysis, B.A.A., F.O.N. and S.A.O.; investigation, F.O.N.; resources, B.A.A. and F.O.N.; data curation, F.O.N.; writing—original draft preparation, B.A.A., F.O.N., O.A.A. and S.A.O.; writing—review and editing, B.A.A., F.O.N., O.A.A. and S.A.O.; visualization, B.A.A., F.O.N., O.A.A. and S.A.O.; supervision, B.A.A. and S.A.O.; project administration, B.A.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data are contained within the article.

Acknowledgments: This work was technically supported by the Department of Food Technology, University of Ibadan; the National Horticultural Research Institute (NIHORT); and the Central Research Laboratory, all in Ibadan, Oyo State, Nigeria.

Conflicts of Interest: The authors declare no conflicts of interest.

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