



Functional low-glycemic ice cream with coconut milk, tiger nut milk, and orange peel powder: Lipid profile modulation in high-fat diet-fed rats

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Received 14.07.2025; Revised 24.09.2025; Accepted 01.09.2026; Published online 28.10.2026

Abstract:

The article introduces a novel low-glycemic-index ice cream targeted at improving the lipid profile and managing oxidative stress. Conventional dairy components were replaced with non-dairy natural sources, i.e., coconut (*Cocos nucifera* L.) and tiger nut (*Cyperus esculentus* L.). The research focused on the effect of this substitution on the sensory, glycemic, and hypocholesterolemic properties of the functional ice cream.

The experimental formulations combined dairy components (whipping cream, skimmed milk), coconut milk, tiger nut milk, and orange (*Citrus × sinensis* (L.) Osbeck) peel powder. The samples were evaluated for their glycemic index, total phenolics, total flavonoids, amylose, and amylopectin contents. The developed formulations were fed to high-fat diet-fed rats for 21 days to assess their lipid profile, as well as the levels of malondialdehyde and reactive oxygen species.

The rats fed the ice cream formulated with coconut milk, tiger nut milk, and orange peel powder demonstrated lower total cholesterol, triglycerides, and low-density lipoprotein cholesterol levels while the high-density lipoprotein cholesterol level was increased. Higher concentrations of coconut milk, tiger nut milk, and orange peel powder correlated with reduced malondialdehyde and reactive oxygen species levels in the rat plasma. They were also associated with a lower glycemic index whereas the phenolic content and amylose-to-amylopectin ratio were significantly higher.

The partial or total replacement of dairy components with coconut milk and tiger nut milk combined with orange peel powder produced ice creams with acceptable sensory properties, a reduced glycemic index, and improved hypocholesterolemic properties.

Keywords: Cholesterol, dairy, glycemic index, orange peels, oxidative stress

Please cite this article in press as: Ademosun AO, Ajeigbe OF, Adewusi ME, Oboh G. Functional low-glycemic ice cream with coconut milk, tiger nut milk, and orange peel powder: Lipid profile modulation in high-fat diet-fed rats. Foods and Raw Materials. 2028;16(1):15–24. <https://doi.org/10.21603/2308-4057-2028-1-726>

INTRODUCTION

Ice cream is one of the most popular desserts globally, available in supermarkets, convenience stores, cafes, restaurants, and from street vendors or ice cream carts. It comes in a variety of flavors and portion sizes to satisfy a broad consumer base [1]. Furthermore, ice cream production methods are diverse, ranging from home-made varieties for personal consumption to large-scale factory manufacturing. However, its high sugar, calorie, and saturated fat content often links ice cream to health complications, including obesity, indigestion, cardiovascular diseases, and type 2 diabetes [2].

Healthy food is important for health-conscious consumers, attempting to prevent or control degenerative

diseases. Logically, enthusiasts of ice cream are concerned with the way ice cream may affect their health, particularly their lipid profile. The glycemic index is a quick way to determine the effect of food on blood glucose because it measures how much a food sample raises blood glucose compared to a reference food [3]. Eating junk food with a high glycemic index causes “increased hunger and reduced energy expenditure” because it increases the post-meal ratio of serum insulin to glucagon [4]. Frequent consumption of high-glycemic-index foods is a risk factor for diabetic, obese, and cardiovascular patients [5]. Consequently, a low-glycemic-index diet is linked to several health advantages [6] as it lowers blood glucose levels, which, in turn, lowers

acetyl-CoA (Coenzyme A) involved in the first step in the mevalonate pathway for cholesterol synthesis, ultimately reducing cholesterol generation. Amylose and amylopectin are the two polymers that make up starch. The amylose-to-amylopectin ratio and dietary fibre are essential elements that define the glycemic index of foods [7]. A lower glycemic index and, as a result, a slower rise in blood glucose levels stem from a slower rate of enzymatic breakdown of carbohydrates. Additionally, a low-glycemic-index diet is advised for the management and prevention of cardiovascular disease and hypercholesterolemia [8].

The risk factors that define the severity of hypercholesterolemia include low high-density lipoprotein cholesterol and high low-density lipoprotein cholesterol and triglycerides. They are commonly evaluated using lipid profile assays [9]. Malondialdehyde and reactive oxygen species are two additional oxidative indicators that shed light on the pathogenesis of hypercholesterolemia [10]. Disequilibrium between the antioxidant defense system and reactive oxygen species generation causes oxidative stress [11]. Hypercholesterolemia raises oxidative stress levels, which can trigger a number of cardiovascular disorders [12]. Oxidized low-density lipoprotein cholesterol particles can occur as a result of elevated low-density lipoprotein cholesterol, causing hypercholesterolemia. Because of their high reactivity, these particles produce reactive oxygen species, which can harm the endothelial cells that line blood arteries. This damage may lead to atherosclerosis, which narrows blood arteries and limits blood flow to essential organs, including the heart and brain [13]. A low-glycemic-index diet of antioxidant foods possesses numerous health advantages. The pathophysiology of some medical conditions is associated with the uncontrolled activity of reactive oxygen species generated during metabolic reactions in the body [14].

This article introduces novel low-glycemic ice cream with partial or complete substitution of milk with non-dairy sources. We examined the glycemic indices of the ice cream, as well as its impact on the lipid profiles and antioxidant status of hypercholesterolemic rats. Additionally, we measured the impact of adding orange peel powder on the health benefits of the new product.

STUDY OBJECTS AND METHODS

Samples and reagents. Tiger nuts (*Cyperus esculentus* L.), coconuts (*Cocos nucifera* L.), oranges (*Citrus × sinensis* (L.) Osbeck), and dates were procured from commercial market. Conventional ice cream was purchased from a commercial creamery near the campus of the Federal University of Technology (Akure, Nigeria). Whipping cream and skim milk were obtained from a local supermarket. Other chemicals and reagents were of analytical grade. Water used in the experiments was glass distilled.

Ice cream formulations. The tiger nuts, oranges, and dates were washed. The outer peel of the oranges was removed with a knife, maintaining a precise depth of 2 mm. The date and orange peel was dried in an oven

at 50°C for 72 and 120 h, respectively, to be blended in a grinding machine into free-flowing powder. The date powder served as sweetener. We broke the coconut to remove the shell and used a knife to remove the testa. Next, we shredded the endocarp with a kitchen shredder and blended it with 300 mL of water for 180 min. Thereafter, the blended sample was strained using a nut milk bag. After being soaked in water for 24 h at 25°C, the tiger nuts were drained, ground in a food processor, and blended with water until the mix turned milky. The resulting milky liquid was then strained using a nut milk bag. Lastly, we prepared the experimental ice cream samples in an ice cream maker. The formulations were as follows:

- 100 g whipping cream + 100 g skim milk + 5 g date powder;
- 75 g whipping cream + 75 g skim milk + 25 g coconut milk + 25 g tiger nut milk + 5 g date powder;
- 50 g whipping cream + 50 g skim milk + 50 g coconut milk + 50 g tiger nut milk + 5 g date powder;
- 25 g whipping cream + 25 g skim milk + 75 g coconut milk + 75 g tiger nut milk + 5 g date powder;
- 100 g coconut milk + 100 g tiger nut milk + 5 g date powder;
- 100 g coconut milk + 100 g tiger nut milk + 5 g date powder + 2.5 g orange peel powder; and
- 100 g coconut milk + 100 g tiger nut milk + 5 g date powder + 5 g orange peel powder.

The commercial ice cream contained milk, cream, sugar, artificial flavorings, and modifying agents (further details were not provided for commercial reasons).

Sensory evaluation. The sensory analysis measured the overall acceptability of the experimental ice cream. The sensory test involved 50 trained male and female panelists of different age groups. They were chosen based on their familiarity and habit of consuming commercial ice cream. All the procedures involving human panelists followed the ethical standards of the Federal University of Technology (Akure, Nigeria) and the 1964 Helsinki Declaration (with amendments). Prior to participation, the panelists were informed about the purpose of the study and provided their informed consent. Participation was entirely voluntary, and the panelists were free to withdraw at any point without any consequence. No physical or psychological harm was expected or reported during the sensory analysis. The data collected were anonymized to ensure confidentiality and used solely for research purposes. The panelists received plates, spoons, drinking water, and a score sheet. The attributes to be recorded included taste, color, texture, aroma, and overall acceptability with a scale range of 1–7, where 1 was equivalent to “very poor” and 7 meant “excellent”.

Total phenols. The total phenol content was determined according to the method [15]. Appropriate dilutions of the samples were oxidized with 2.5 mL of 10% the Folin-Ciocalteu reagent (v/v) and neutralized by 2.0 mL of 7.5% sodium carbonate. The reaction mix was incubated at 45°C for 40 min before we measured the absorbance at 765 nm with a spectrophotometer. The total phenol content was subsequently calculated as gallic acid equivalent.

Total flavonoids. The total flavonoid content was determined using a slightly modified method reported by Meda *et al.* [16]. Briefly, we mixed 0.5 mL of the appropriately diluted sample with 0.5 mL of methanol, 50 μ L of 10% AlCl_3 , 50 μ L of 1 M potassium acetate, and 1.4 mL of water. After incubating the mix at room temperature for 30 min, we determined the absorbance of the reaction mix.

Estimated glycemic index. In testing the *in-vitro* starch hydrolysis rate and glycemic index, we followed the method described by Goni *et al.* [17]. Each sample (50 mg) was incubated with pepsin (1 mg) in 10 mL of HCl–KCl buffer (pH 1.5) at 40°C for 60 min. After that, we added 2.5 mL of phosphate buffer (pH 6.9) and 5 mL of α -amylase solution to the reaction mix. After incubating it at 37°C in a shaking water bath, we took 0.1 mL from each reaction mix at a 30-min interval for 3 h and boiled them to inactivate the enzyme. The residual starch was digested to glucose by 3 mL of α -glucosidase and incubated at 60°C for 45 min. The glucose concentration was assayed by adding 200 mL of 3,5-dinitrosalicylic acid. After stopping the reaction by boiling, we added 5 mL of distilled water to read the absorbance at 540 nm. The rate of starch digestion was expressed as the percentage of starch hydrolyzed per a unit of time.

Amylose and amylopectin content. We added 1 mL of 95% ethanol and 9 mL of 1 N NaOH to 100 mg of each sample in a volumetric flask. The reaction mix was heated in boiling water for 10 min. After that, we added 1 mL of 1 N acetic acid and 2 mL of iodine solution to 5 mL of the solution. After thorough shaking, we measured the absorbance at 620 nm. Amylopectin content was calculated by subtracting the amylose content from the total starch content [18, 19].

Animal experiment. Figure 1 illustrates the research scheme. Male Wistar rats (180–200 g each) were purchased from the Biochemistry Department of the Federal University of Technology, Akure, Nigeria. They were kept in cages at room temperature. Allocated into eleven groups, the animals were allowed to acclimatize for two weeks with access to food and water. The handling of experimental animals followed the ethical guidelines developed by the US National Institute of Health and were approved by the animal ethics committee of the Federal University of Technology (Akure, Nigeria) (FUTA/ETH/21/07). The experimental rats received a high-fat diet for 14 days to induce hypercholesterolemia as described by Oboh *et al.* [20]. Subsequently, the hypercholesterolemic rats were fed with the ice cream for 21 days as shown below:

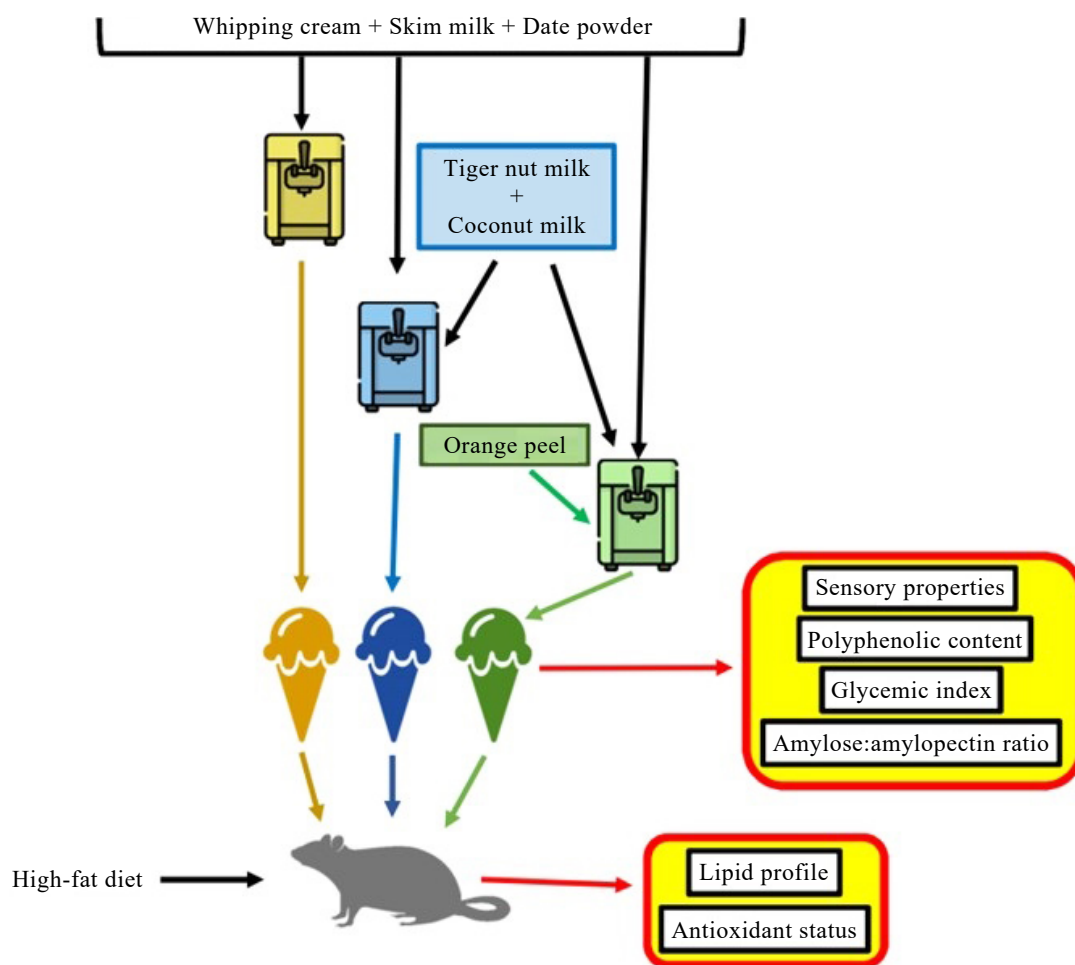


Figure 1 Research scheme

Group 1 – Control (basal diet);

Group 2 – high-fat diet;

Group 3 – high-fat diet + statin (0.2 mg/kg);

Group 4 – high-fat diet + 100 g whipping cream + 100 g skim milk;

Group 5 – high-fat diet + 75 g whipping cream + 75 g skim milk + 25 g coconut milk + 25 g tiger nut milk;

Group 6 – high-fat diet + 50 g whipping cream + 50 g skim milk + 50 g coconut milk + 50 g tiger nut milk;

Group 7 – high-fat diet + 25 g whipping cream + 25 g skim milk + 75 g coconut milk + 75 g tiger nut milk;

Group 8 – high-fat diet + 100 g coconut milk + 100 g tiger nut milk;

Group 9 – high-fat diet + 100 g coconut milk + 100 g tiger nut milk + 2.5 g orange peel powder;

Group 10 – high-fat diet + 100 g coconut milk + 100 g tiger nut milk + 5 g orange peel powder; and

Group 11 – high-fat diet + commercial ice cream.

Plasma. The rats were sacrificed by cervical dislocation after an overnight fast. The blood was taken from the heart into tubes containing ethylene-diaminetetraacetic acid and centrifuged at 10,000×g for 15 min. The supernatant was used for biochemical assays.

Biochemical assays. *Lipid profile.* The lipid profile analysis involved total cholesterol, high-density lipoprotein, low-density lipoprotein, and triglycerides. The data were obtained using Randox assay kits.

Malondialdehyde level. The malondialdehyde content in the blood was assayed as recommended by Ohkawa *et al.* [21]. We added 300 mL of plasma to 300 mL of 8.1% sodium dodecyl sulfate, 500 mL of acetic acid/HCl (pH 3.2), and 0.8% thiobarbituric acid to incubate the mix at 100°C for 1 h. Thereafter, the resulting thiobarbituric acid reactive species was read at 532 nm.

Reactive oxygen species. The level of reactive oxygen species was measured in line with the method developed by Hayashi *et al.* [22]. Briefly, we transferred 50 mL of plasma and 1,400 µL of CH₃COONa buffer (0.1 M; pH 4.8) into a beaker and added 1,000 mL of reagent mix. The reagent mix consisted of 6 mg/mL of N,N-diethyl-para-phenylenediamine and 4.37 µM of ferrous sulphate dissolved in CH₃COONa buffer. The absorbance was read at 505 nm.

Protein content. The protein content was analyzed by the Coomassie blue method utilizing serum albumin as standard [23].

Data analysis. The results of triplicate experiments were pooled and expressed as mean value ± standard deviation. The means were compared using one-way analysis of variance (ANOVA). Significant difference was accepted at $p \leq 0.05$ using GraphPad Prism version 5.00 (Windows) for statistical analysis.

RESULTS AND DISCUSSION

Foods are developed to meet consumer expectations. This compliance can be assessed by the sensory qualities of the finished product [5]. The sensory qualities that demonstrate consumer acceptability include texture, taste, color, and aroma. The commercial ice cream

received the highest scores in terms of texture, taste, color, aroma, and overall acceptability (Fig. 2). Every increase in the amount of coconut milk, tiger nut milk, and orange peel powder correlated with a reduction in the score for texture, taste, color, aroma, and overall acceptability. These results were similar to those reported by Nakov *et al.* [24], who fortified cakes with grape pomace powder: as the percentage of powder in the formulation increased, the score for sensory characteristics went down. Obviously, the deviation from the conventional sensory qualities resulted in the lower sensory quality scores. Consumer expectations usually depend on prior experience, familiarity, and professional recommendations [25]. However, the overall acceptability and marketability of functional foods are also shaped by brand, color, price, and health claims [26].

Table 1 represents the total phenols and flavonoids as an important parameter of health status. The total phenol and flavonoid contents ranged significantly. The commercial sample contained 0.19 mg/g total phenols and 0.05 mg/g total flavonoids. The experimental sample with 100 g of coconut milk, 100 g of tiger nut milk, and 5 g of orange peel powder demonstrated 1.44 mg/g total phenols and 0.74 mg/g total flavonoids. The total phenol and flavonoid contents in the ice creams increased together with the shares of date powder, coconut milk, tiger nut milk, and orange peel powder. The result was anticipated as these natural products were had been chosen for their high content of bioactive compounds, e.g.,

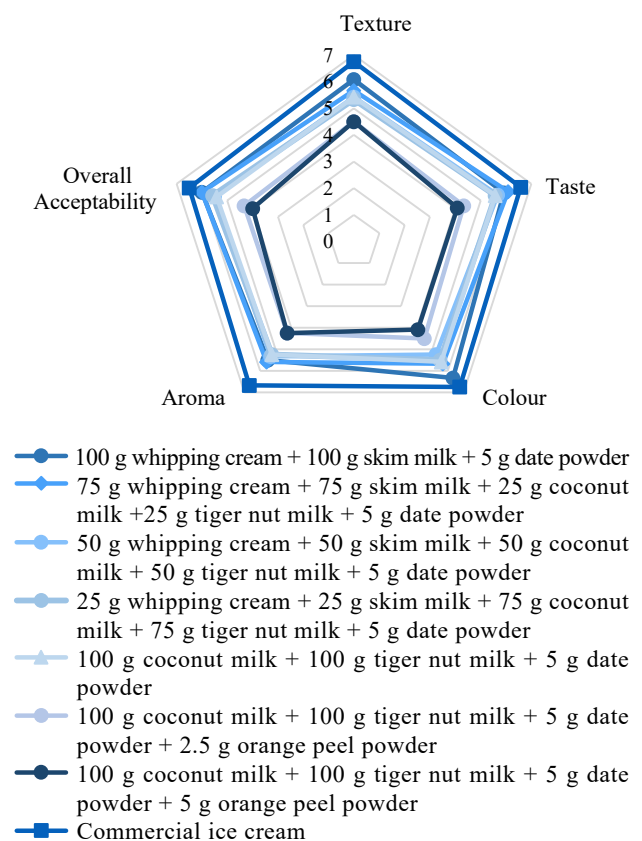


Figure 2 Sensory properties of ice cream samples: Mean value ± standard deviation, n = 3

Table 1 Total phenols, total flavonoids, sugar, starch, amylose, and amylopectin: Estimated glycemic indices of ice cream samples

Sample	Total phenols, mg GAE/g	Total flavonoids, mg QE/g	Glycemic index	Amylose, %	Amylopectin, %	Amylose/ amylopectin
100 g whipping cream + 100 g skim milk + 5 g date powder	0.42 ± 0.03 ^a	0.24 ± 0.01 ^a	49.31 ± 2.82 ^a	18.43 ± 0.45 ^a	81.57 ± 0.63 ^a	0.23
75 g whipping cream + 75 g skim milk + 25 g coconut milk + 25 g tiger nut milk + 5 g date powder	0.51 ± 0.01 ^b	0.27 ± 0.01 ^b	42.23 ± 1.41 ^b	20.46 ± 0.73 ^b	79.54 ± 0.56 ^b	0.26
50 g whipping cream + 50 g skim milk + 50 g coconut milk + 50 g tiger nut milk + 5 g date powder	0.55 ± 0.02 ^c	0.29 ± 0.00 ^c	39.10 ± 1.42 ^c	23.43 ± 0.97 ^c	76.57 ± 0.87 ^c	0.31
25 g whipping cream + 25 g skim milk + 75 g coconut milk + 75 g tiger nut milk + 5 g date powder	0.64 ± 0.02 ^d	0.34 ± 0.01 ^d	38.04 ± 1.02 ^d	24.87 ± 0.74 ^d	75.13 ± 0.31 ^d	0.33
100 g coconut milk + 100 g tiger nut milk + 5 g date powder	0.81 ± 0.02 ^e	0.48 ± 0.01 ^e	37.51 ± 2.02 ^e	26.59 ± 0.54 ^e	73.41 ± 0.57 ^e	0.36
100 g coconut milk + 100 g tiger nut milk + 5 g date powder + 2.5 g orange peel powder	1.06 ± 0.09 ^f	0.56 ± 0.02 ^f	33.54 ± 2.22 ^f	27.91 ± 0.53 ^f	72.09 ± 0.62 ^f	0.39
100 g coconut milk + 100 g tiger nut milk + 5 g date powder + 5 g orange peel powder	1.44 ± 0.01 ^g	0.74 ± 0.01 ^g	32.58 ± 2.07 ^g	29.32 ± 0.47 ^g	70.68 ± 0.42 ^g	0.41
Commercial ice cream	0.19 ± 0.01 ^h	0.05 ± 0.01 ^h	69.02 ± 3.04 ^h	16.43 ± 0.71 ^h	83.57 ± 0.51 ^h	0.20

Values with the same superscript letter in the same column are not significantly different ($p < 0.05$)

Values represent mean ± standard deviation, n = 3

polyphenols [27–29]. Coconut milk, tiger nut milk, date powder, and orange peel are popular ingredients in functional anti-degenerative foods. They are rich in polyphenols that offer health benefits by improving antioxidant defenses and regulating enzymes that help manage chronic diseases [30].

Table 1 shows the glycemic indices of the ice cream samples. The commercial ice cream had the highest glycemic index (69.02) compared to the other ice cream samples, which ranged from 32.58 to 49.31. Similarly, the amylose content of the commercial ice cream (16.43%) was significantly lower than in the other samples (from 18.43 to 29.32%). The amylopectin content ranged from 70.68% in the sample with 100 g coconut milk, 100 g tiger nut milk, and 5 g orange peel of powder to 83.57% in the commercial ice cream sample. The amylose-to-amylopectin ratio ranged from 0.20 in the commercial sample to 0.41 in the sample with 100 g coconut milk, 100 g tiger nut milk, and 5 g orange peel of powder. The glycemic indices of the formulated ice cream samples reduced with every increase in the amount of coconut milk, tiger nut milk, and orange peel powder. These natural products are known to possess low glycemic indices, as well as a high amylose-to-amylopectin ratio.

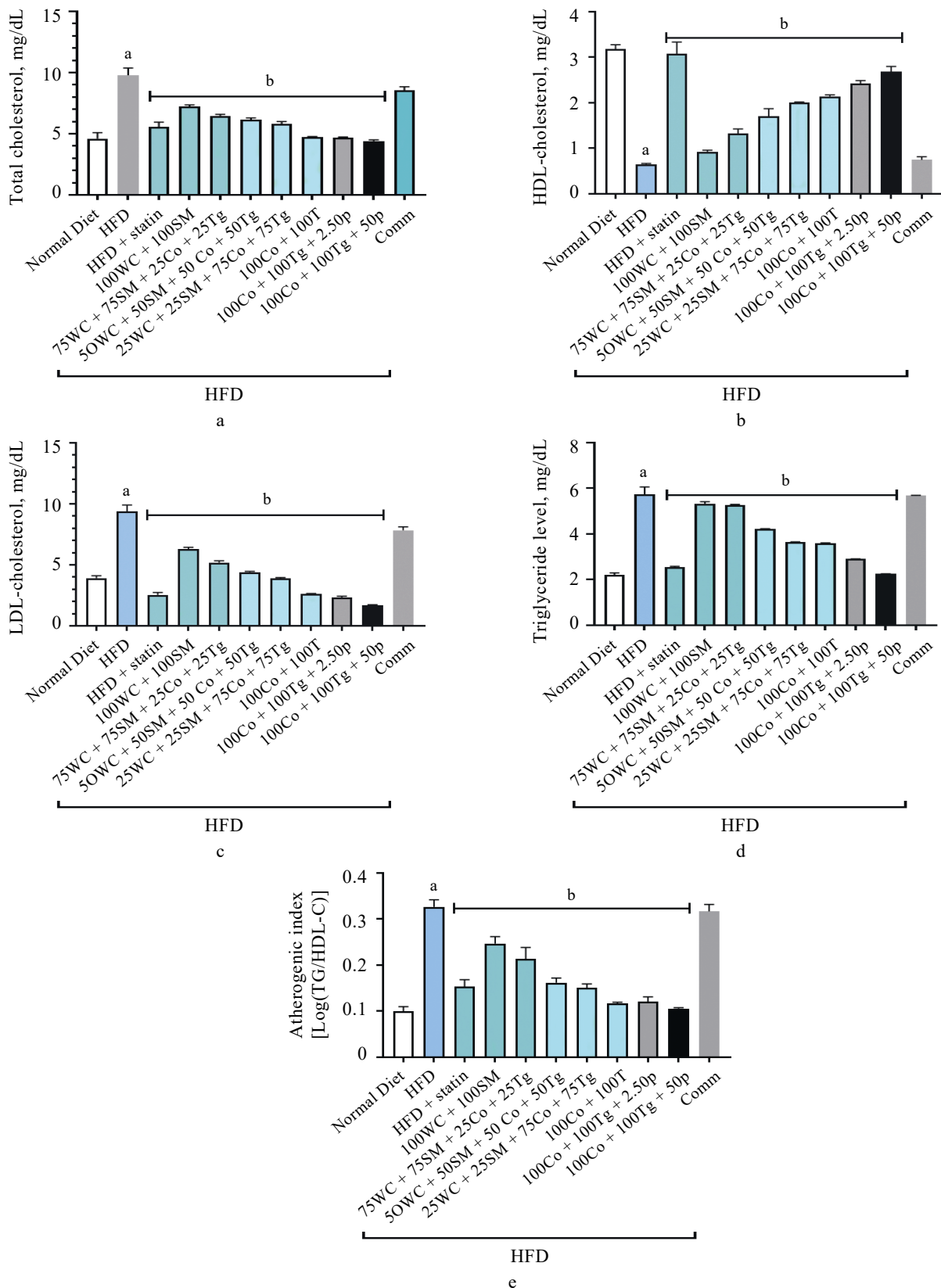
Interestingly, the glycemic indices were inversely proportional to the amylose-to-amylopectin ratio. According to Ademosun *et al.* [8], a higher amylose concentration lowers the glycemic index by delaying the breakdown of starch. Furthermore, the complexes formed by the amylose and lipids in ice cream are more resilient to hydrolytic enzyme attack [3]. These results suggest that the ice creams formulated with coconut milk, tiger nut

milk, and orange peel powder are ideal for the management of postprandial hyperglycemia. Low-glycemic-index diets also prevent and manage hypercholesterolemia and cardiovascular diseases [31]. A low-glycemic-index diet results in lower blood glucose and, consequently, lower acetyl-CoA (Coenzyme A), which is involved in the first reaction in the mevalonate pathway for cholesterol synthesis. In turn, low acetyl-CoA leads to reduced cholesterol biosynthesis [5].

The results of the plasma cholesterol (Fig. 3a), high-density lipoprotein cholesterol (Fig. 3b), low-density lipoprotein cholesterol (Fig. 3c), triglyceride levels (Fig. 3d), and atherogenic index (Fig. 3e) revealed that high-fat diet significantly increased all these parameters. The commercial ice cream had the highest total cholesterol, low-density lipoprotein cholesterol, triglyceride, and atherogenic index, as well as the lowest high-density lipoprotein cholesterol. However, increased shares of coconut milk, tiger nut milk, and orange peel powder caused reduction of total cholesterol, low-density lipoprotein cholesterol, triglyceride, and atherogenic indices in the plasma.

The fortified ice cream samples also showed increased high-density lipoprotein cholesterol levels compared to the commercial ice cream and the untreated rats on a high-fat diet. The results agree with some previous publications that reported a negative correlation between a high-glycemic-index diet and high levels of high-density lipoprotein cholesterol [32, 33].

Lipid profile, lipid ratio, and atherogenic index are potential predictors of glycemic control [34] as we observed high total cholesterol, high low-density lipoprotein cholesterol, and lower high-density lipoprotein



HFD – high-fat diet; 100WC + 100SM – 100 g whipping cream + 100 g skim milk + 5 g date powder; 75WC+75SM + 25Co + 25Tg – 75 g whipping cream + 75 g skim milk + 25 g coconut milk + 25 g tiger nut milk + 5 g date powder; 50WC + 50SM + 50Co + 50Tg – 50 g whipping cream + 50 g skim milk + 50 g coconut milk + 50 g tiger nut milk + 5 g date powder; 25WC + 25SM+75Co + 75Tg – 25 g whipping cream + 25 g skim milk + 75 g coconut milk + 75 g tiger nut milk + 5 g date powder; 100Co + 100Tg – 100 g coconut milk + 100 g tiger nut milk + 5 g date powder; 100Co + 100Tg + 2.5Op – 100 g coconut milk + 100 g tiger nut milk + 5 g date powder + 2.5 g orange peel powder; 100Co + 100Tg + 5Op – 100 g coconut milk + 100 g tiger nut milk + 5 g date powder + 5 g orange peel powder; Comm – Commercial ice cream

Figure 3 Effect of experimental ice cream samples on: Plasma total cholesterol (a), plasma high-density lipoprotein cholesterol (b), plasma low-density lipoprotein cholesterol (c), triglycerides (d), and atherogenic indices (e) in rats on a high-fat diet

cholesterol levels in the rats fed with the high-glycemic-index ice cream. Similarly, patients with hyperlipidemia were reported to possess decreased levels of triacylglycerol and low-density lipoprotein cholesterol following a month of low glycemic index diet [35]. Therefore, the ability of the experimental ice cream to reduce plasma total cholesterol and low-density lipoprotein cholesterol could be linked to the low glycemic index.

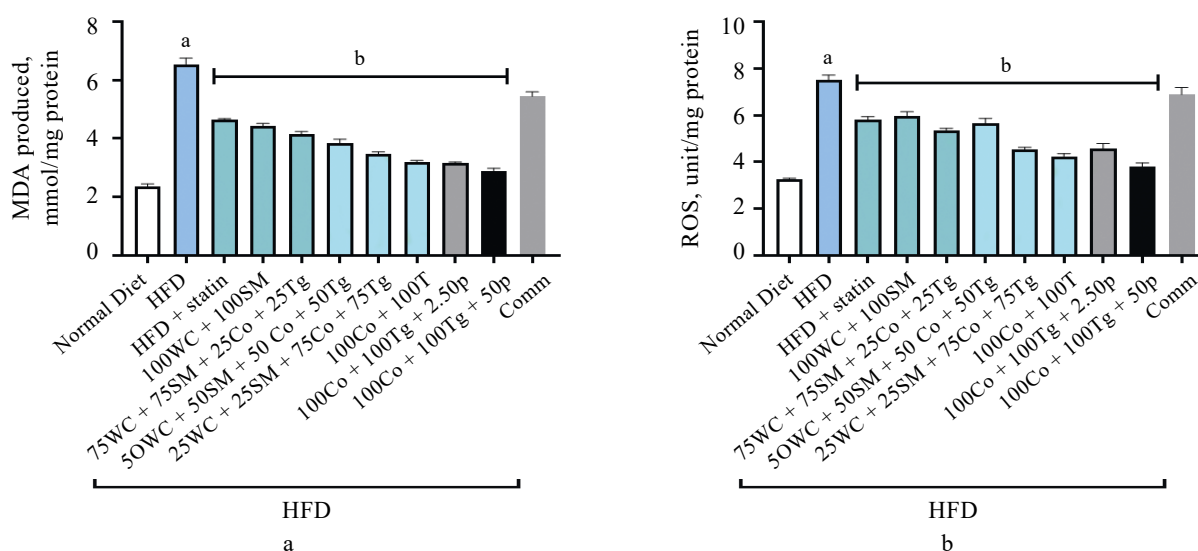
However, lipid profiles are a useful marker of glycemic control in patients with hypercholesterolemia or type 2 diabetes [34]. For instance, obese female patients on a high-glycemic-index diet demonstrated increased triglycerides and decreased high-density lipoprotein levels [36]. In our case, the ability of the experimental ice cream to modulate lipid profile shows that they could be classified as potential functional foods for improving glycemic control in patients with hypercholesterolemia. The individual contributions of the natural products contributed to the synergetic ability of the ice cream to lower total cholesterol and low-density lipoprotein cholesterol while improving high-density lipoprotein cholesterol. Coconuts, tiger nuts, orange peel, and dates were earlier reported as effective ingredients in maintaining a healthy lipid profile [8, 37].

Consumption of low-glycemic-index diets by diabetic patients led to significant reduction in total cholesterol and low-density lipoprotein cholesterol, compatible to the effects of synthetic hydroxyl-methyl-glutaryl-CoA reductase inhibitors [35]. Interestingly, orange peel possesses bioactive compounds that inhibit hydroxyl-methyl-glutaryl-CoA reductase. Thus, the higher cholesterol lowering abilities of the samples with maximal amounts of coconut milk, tiger nut milk, and 2.5 or 5 g of orange peel powder could be attributed to the low glycemic in-

dex of the experimental ice cream samples and the cholesterol-lowering ability of orange peel. The high-fat diet increased triglyceride concentration in the rats. According to Tan & Norhaizan [38], elevated chylomicron levels in the intestine stimulate the generation of fatty acids, which are subsequently esterified into triglycerides. However, the triglyceride levels reduced significantly in the rats fed with the experimental ice creams. The reduction in triglyceride levels correlated with the increasing amounts of coconut milk, tiger nut milk, and orange peel powder. This phenomenon suggests that the reduction in glycemic index and/or improvement in antioxidant status could be responsible for the reduction in triglyceride levels. For instance, a low-glycemic-index diet was able to reduce serum triglycerides by 15–25% [39], which supports the triglyceride-lowering effect of the experimental low-glycemic-index ice cream. Furthermore, orange peel flavonoids are known to reduce cholesterol and triglyceride concentrations in experimental animals [40].

Figures 4a and 4b show the effects of the ice cream samples on malondialdehyde and reactive oxygen species generation in the rats subjected to a high-fat diet. The high-fat diet boosted the production of malondialdehyde and reactive oxygen species while the experimental samples with coconut milk, tiger nut milk, and orange peel powder reduced it. Malondialdehyde is a marker for lipid peroxidation, which was reported to increase on a high-fat and high-glycemic-index diet [41]. This effect was evidenced in our study by the malondialdehyde concentration in the rats on a high-fat diet alone and the rats that received commercial ice cream.

Low-glycemic-index diets protect against lipid peroxidation because a slower release of glucose from foods may prevent the high-glucose-linked oxidative stress



MDA – malondialdehyde; ROS – reactive oxygen species; HFD – high-fat diet; 100WC + 100SM – 100 g whipping cream + 100 g skim milk + 5 g date powder; 75WC + 75SM + 25Co + 25Tg – 75 g whipping cream + 75 g skim milk + 25 g coconut milk + 25 g tiger nut milk + 5 g date powder; 50WC + 50SM + 50Co + 50Tg – 50 g whipping cream + 50 g skim milk + 50 g coconut milk + 50 g tiger nut milk + 5 g date powder; 25WC + 25SM + 75Co + 75Tg – 25 g whipping cream + 25 g skim milk + 75 g coconut milk + 75 g tiger nut milk + 5 g date powder; 100Co + 100Tg – 100 g coconut milk + 100 g tiger nut milk + 5 g date powder; 100Co + 100Tg + 2.5Op – 100 g coconut milk + 100 g tiger nut milk + 5 g date powder + 2.5 g orange peel powder; 100Co + 100Tg + 5Op – 100 g coconut milk + 100 g tiger nut milk + 5 g date powder + 5 g orange peel powder; Comm – Commercial ice cream

Figure 4 Effect of experimental ice cream samples on: Malondialdehyde (a) and reactive oxygen species (b) in rats on a high-fat diet

and the consequent lipid peroxidation [42]. Furthermore, a human study involving 292 healthy adults demonstrated that dietary glycemic index had positive correlation with malondialdehyde level in plasma [41]. Therefore, our low-glycemic-index ice creams reduced the malondialdehyde level in the rats that consumed them whereas the rats that ate commercial ice cream with the highest glycemic index demonstrated significantly higher malondialdehyde levels. In addition, orange peel is known to inhibit lipid peroxidation in various tissues [30]. In our study, the inclusion of orange peel in the ice cream formulations also caused a dose-dependent inhibition of lipid peroxidation.

High-fat diet correlates with elevated reactive oxygen species generation, closely linking high fat intake with disease progression [43]. The management of oxidative damage occurs through increased consumption of antioxidant-rich diets, which are crucial in combating reactive oxygen species [44].

Our experimental ice cream with coconut milk, tiger nut milk, and orange peel powder caused significant reduction in the reactive oxygen species generation in the laboratory rats. This reduction inversely correlated with the total phenolic and flavonoid contents in the ice cream and directly correlated with its glycemic index.

In other studies, higher lipid peroxidation and reactive oxygen species reduced the amount of antioxidant enzymes, thus leading to increased oxidative damage and attendant consequences [14]. Therefore, consuming bioactive foods with antioxidative properties helps to mitigate the deleterious effects of excessive lipid peroxidation and reactive oxygen species generation. In addition, a depletion of serum antioxidants usually correlates with an increase in the postprandial glucose concentra-

tion [41]. Therefore, diets rich in antioxidants facilitate glycemic management while low-glycemic-index diets improve the antioxidant status [35].

CONCLUSION

We elevated conventional ice cream to a functional status by replacing its dairy components with coconut milk and tiger nut milk while fortifying it with orange peel powder. These modifications reduced the glycemic indices and improved the phenolic content of the experimental ice cream. Furthermore, the functional ice cream improved the lipid profile, reduced the lipid peroxidation, and lowered the reactive oxygen species generation in rats subjected to a high-fat diet.

The novel coconut and tiger nut milk ice cream fortified with orange peel powder presents a promising dietary option for the management of oxidative stress and hypercholesterolemia in human patients. However, this formulation requires further *in vivo* research and clinical studies.

CONTRIBUTION

A.O. Ademosun designed and performed the analysis and wrote the manuscript; O.F. Ajeigbe contributed the data and analysis tools and wrote the manuscript; M.E. Adewusi performed the analysis and wrote the paper; G. Oboh developed the research concept, designed the experiments, and wrote the manuscript.

CONFLICT OF INTEREST

The authors declared no potential conflict of interest regarding the research, authorship, and/or publication of this article.

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