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Triple Fortification of Coconut Milk Chocolate Drinks with Iron, Iodine, and Vitamin A: A Novel Approach to Nutritional Intervention in Resource-Limited Settings

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ABSTRACT: This study investigated the production and quality evaluation of fortified and non-fortified coconut milk chocolate drinks with varying sugar and cocoa powder levels. The goal was to reduce post-harvest losses of locally available coconut fruits and cocoa beans by processing them into nutritious drinks. These drinks could serve as a vehicle for micronutrient fortification and thus, help to reduce protein energy malnutrition and micronutrient deficiency that are prevalent amongst children and pregnant mothers in sub-Saharan African countries. All raw materials for the production of drinks were processed using standard good manufacturer and good hygienic practices (GMP and GHP). Chocolate drinks were formulated as: PCCNF (plain coconut milk chocolate non-fortified), PCCF (plain coconut milk chocolate fortified), SCCNF (sweetened coconut milk chocolate non-fortified), and SCCF (sweetened coconut milk chocolate fortified) drinks. Drinks were subjected to triple fortification using KI, FeSO4, and retinol palmitate as recommended by world food fortification programs. All formulations underwent proximate, vitamin, and mineral quality analyses using standard methods. Cocoa powder and the addition of fortificants led to a statistically significant increase (*P*<0.05) in the proximate composition, particularly in protein and carbohydrate of 3.4-4.0 and 4.8-5.6 g/100 g, respectively. Fortification with KI, FeSO4 and retinol palmitate increased potassium (150-264 mg/100 g), iron level spanned (2.9-3.4 mg/100 g), iodine (0.16-0.38 mg/100 g) and pro vitamin A (1.7-2.5 mg/100 g of drinks as seen in PCCF and SCCF (fortified drinks) compared to non-fortified versions (PCCNF and SCCNF). The study concluded that these drinks were suitable vehicles for micronutrient (iodine, iron, and provitamin A) fortification and protein-energy malnutrition intervention programs.

Keywords: coconut milk, chocolate drinks, micronutrient fortification, protein-energy malnutrition, and post-harvest losses

INTRODUCTION

Coconut milk, a plant-based milk alternative derived from the coconut fruit, has gained global popularity due to increasing vegetarianism, rising lactose intolerance, and perceived health benefits (Abdullah *et al*., 2022). It is nutritionally dense, delivering 552 kcal per serving with a high fat content (57.1 g), moderate protein (5.5 g), and vital minerals like potassium (631 mg) and magnesium (88.8 mg). Notably rich in lauric acid, a type of medium-chain fatty acid linked to cardiovascular benefits, coconut milk has also been associated with weight loss promotion and cholesterol reduction (Tulashie *et al*., 2022). Chocolate beverages prepared using cocoa powder, milk or water, and sweeteners provide high-quality proteins, essential vitamins (A, B_1, B_2, D), and minerals like calcium, phosphorus, magnesium, and zinc (Marta *et al*., 2023). To qualify as a chocolate drink, the product must contain at least 0.5% cocoa by weight (Indiarto *et al*., 2022), and is typically produced through homogenization with various ingredients. As defined by the World Health Organization, food fortification is the deliberate addition of macro- and micronutrients to foods to address population-level deficiencies, particularly those related to iodine, iron, and vitamin A (WHO, 2021; Saleh *et al*., 2018). This strategy has been recognized as a safe and cost-effective means of improving dietary quality and preventing nutritional deficiencies, especially in regions like Sub-Saharan Africa (Brouwer *et al*., 2021).

This study addresses a complex set of interrelated challenges prevalent in Sub-Saharan Africa, including protein-energy malnutrition (PEM), widespread micronutrient deficiencies, often termed "hidden hunger", substantial post-harvest losses, and the limited availability of effective fortification vehicles (Mkambula *et al*., 2020). At-risk groups, including children and expectant mothers, are disproportionately affected, facing stunted growth, impaired cognitive development, heightened susceptibility to disease, and elevated mortality rates (Akombi *et al*., 2017; Senbanjo *et al*., 2022; WHO, 2024). At the same time, the region suffers significant losses of agricultural commodities like coconut and cocoa, which, if processed effectively, could serve as nutrient-rich bases for fortified food products (Chakona & Shackleton, 2019; WHOROA, 2024). By exploring the potential of coconut milk–based chocolate drinks as a vehicle for fortification, this study seeks to transform underutilized resources into functional foods that address pressing nutritional deficits, minimize food waste, and enhance access to adequate food, an endeavor of both regional importance and global relevance (WVI, 2025).

This study aimed to develop and evaluate fortified coconut milk chocolate drinks as a nutritional intervention strategy to combat protein-energy malnutrition and micronutrient deficiencies, while simultaneously addressing the significant post-harvest losses of coconut fruits and cocoa beans in Sub-Saharan Africa. This research targeted critical nutritional challenges, such as iron, iodine, and vitamin A deficiencies, that have a greater impact on at-risk populations, such as children under five years of age and expectant mothers. To achieve this, the study formulated coconut milk chocolate drinks with varying compositions of sugar and cocoa powder to optimize both palatability and nutritional value. It further implemented a triple fortification approach using potassium iodide (KI), ferrous sulfate ($FeSO_4$), and retinol palmitate to directly address key micronutrient deficiencies. A comprehensive nutritional analysis was conducted, assessing proximate composition, vitamin levels, and mineral content, while comparing fortified and non-fortified versions of both plain and sweetened formulations. The study also evaluated the potential of these drinks to serve as effective fortification vehicles in accordance with international food fortification standards. By leveraging locally available and culturally familiar ingredients, this research contributed to reducing food waste through value addition, promoted food security, and supported sustainable development (Beal *et al*., 2024). Ultimately, it offers a scalable, community-based model aligned with global health priorities and the Sustainable Development Goals, merging traditional food systems with innovative nutritional solutions (WHO, 2023; UNICEF, 2023).

MATERIALS AND METHODS

Materials

Primary ingredients such as fresh coconut fruits, cocoa powder, and sugar were obtained from a supermarket in Makurdi, Benue State, Nigeria. Analytical food-grade fortificants (Potassium Iodide, Ferrous Sulfate, and Retinol Palmitate) were sourced from a certified chemical supplier in Makurdi, Benue State, Nigeria. Primary and secondary packaging materials were acquired from Modern Market in Makurdi, Benue State, Nigeria. All raw materials and fortificants were inspected upon receipt to ensure compliance with food safety standards and were stored under appropriate conditions according to manufacturer specifications prior to processing. All materials were sourced locally within Makurdi, Benue State, Nigeria, to support local commerce and ensure the freshness of perishable ingredients.

Cocoa Powder Production

Cocoa powder was produced following Setiadi et al. (2021) method. The process involved sorting and cleaning cocoa beans, roasting them at 175 °C for 10 min, and dehulling and winnowing (Setiadi et al., 2021). The seeds were then crushed and ground into a paste, which was hydraulically pressed to extract cocoa butter. The resulting cake was dried at 60 °C for 24 h, then crushed, ground, and sieved through a 0.5 mm mesh. The final product was sealed in polyethylene bags and kept in sealed PET containers at ambient temperature for later use in chocolate drink production.

Coconut Milk Preparation

Coconut milk was produced according to Patil Benjakul et al. (2018) method. Mature coconuts were manually deshelled, and the endocarp was cracked using stainless steel knives. The white coconut meat was extracted by paring off the brown skin, then rinsed to remove impurities. The clean meat was sliced into 3 mm thick pieces, then ground into a smooth paste using an electric blender (Patil & Benjakul, 2018). Milk was extracted by pressing the paste through a cheesecloth, then filtered to remove sediments. The milk underwent pasteurization at 70 °C for 15 min, then was cooled, bottled, and stored under refrigeration at 2-4 °C until further use (Patil & Benjakul, 2018).

Chocolate drinks formulation

Beverage formulations were created using a randomized experimental design. The drinks were prepared by adjusting the ratios of cocoa powder, coconut milk, and sugar as illustrated in Table 1. The design incorporated two different amounts of cocoa powder (0.2 and 0.4% w/v) and two varying concentrations of sugar. This yielded 4 experimental samples that were subjected to sensory evaluation to obtain the 2 most preferred samples. The 2 most preferred samples were selected from the group with zero sugar (for diabetes patients) and the group with sugar and fortified to obtain 4 experimental samples as illustrated in Table 1. The drinks formulations were fortified with 0.15 mg Potassium Iodide (KI), 2.0 mg Ferrous Sulphate ($FeSO_4$), and 1.6 mg retinol palmitate per 100 g of sample using standard fortification guidelines recommended by the Food Fortification Regulation with micronutrients (Regulations, 2021).

Table 1. Sample formulation for fortified and non-fortified chocolate drink samples

	Ingredients (%)			
Samples	Coconut milk	Cocoa powder	Sugar	Fortification
PCCNF	99.8	0.2	0	Non-fortified
PCCF	99.8	0.2	0	Fortified
SCCNF	95.6	0. 4	4	Non-fortified
SCCF	95.6	0. 4	4	Fortified

Key:
PCCNF: Plain Coconut Chocolate Non-Fortified drink
PCCF: Plain Coconut Chocolate Fortified drink
SCCNF: Sweetened Coconut Chocolate Non-Fortified drink
SCCF: Sweetened Coconut Chocolate Fortified drink

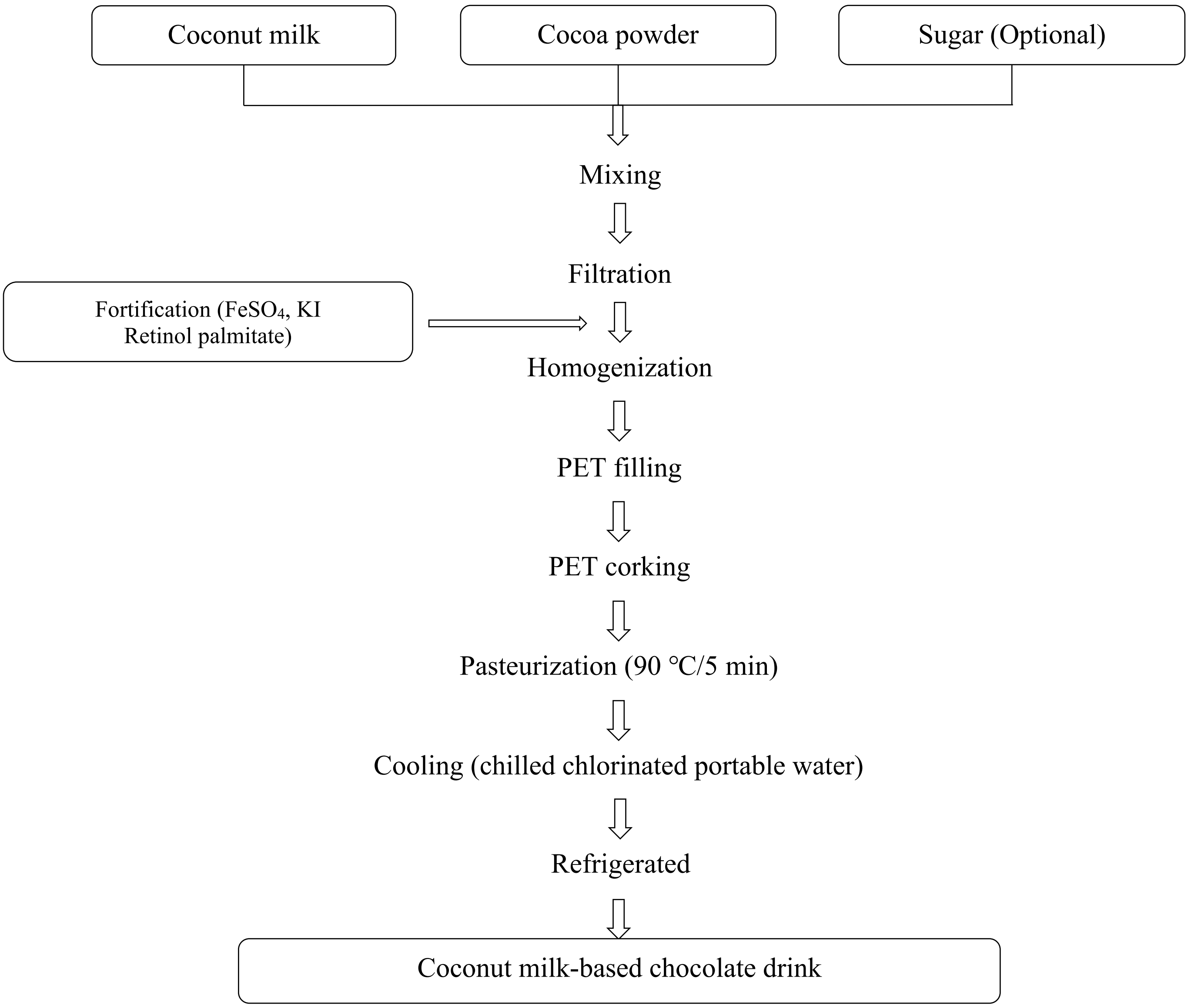

Figure 1. Flow chart for the production of coconut milk-based chocolate drink (Yakum *et al*., 2024)

Preparation of Coconut-Chocolate Beverages

The coconut milk chocolate beverages were crafted by combining cocoa powder, coconut milk, and sugar in ratios, as depicted in Table 1. These formulations were then mixed and processed into a fortified coconut milk-based chocolate drink, as illustrated in Figure 1. During the mixing process, sugar was optionally incorporated. To ensure purity, the mixture underwent filtration to remove any potential contaminants that may have been introduced during the blending stage. Homogenates were bottled in rigid airtight 50 cL Polyethylene Terephthalate containers and pasteurized at 90 °C for 5 min, followed by cooling and refrigerated for 1 h to achieve serving temperature for drinks, then subjected to quality analysis.

Quality analysis of formulated samples

The formulated samples were subjected to the following quality analysis

Physicochemical analysis of coconut milk chocolate drink

All the formulated samples were analyzed for physicochemical properties as follows:

pH analysis: The pH of each formulated sample was measured using a digital pH meter. 15 mL of the sample was placed in a beaker, and the pH meter probe was immersed in the liquid. The pH value was then read and recorded (AOAC, 2010).

Titratable acidity: The lactic acid content was assessed following the AOAC (2010) method. The process involved titrating the sample with 0.1 M NaOH, using phenolphthalein as an indicator (AOAC, 2010).

Determination of specific gravity: A digital hydrometer was used to determine the specific gravity, where 10 mL of the sample was placed in a flask. A hydrometer was inserted into the liquid and allowed to stabilize until foaming ceased. The value was read from the scale of the hydrometer, which displays specific gravity measurements at various intervals. The value corresponding to the water line mark was recorded (Khuenpet et al., 2016).

Determination of proximate composition: Proximate composition analysis was conducted in triplicate to evaluate moisture, ash, protein, fat, and crude fiber concentrations using AOAC (2012) methods. Total carbohydrate levels were calculated by deducting the sum of fat, moisture, ash, crude fiber, and protein percentages from 100. Solid non-fat content was determined by subtracting the fat component from the dry matter. Energy content was computed using conventional calculation approaches.

Vitamin and mineral determination: Vitamin content (A, B_1, B_2, C, and K) in the drink samples was assessed using spectrophotometric methods as outlined by (Aremu & Nweze, 2017)). Mineral content, including calcium, sodium, magnesium, potassium, zinc, iron, and iodine, was determined following the procedure portrayed by Amadou et al. (2020).

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Table 2. Physicochemical characteristics of fortified and non-fortified chocolate beverages

Nutrient (%)	Sample			
	PCCNF	PCCF	SCCNF	SCCF
pH	6.5±0.03^{d}	6.6±0.20^{c}	6.7±0.15^{b}	6.8± 0.01^{a}
TTA (%)	0.4±0.17^{a}	0.35±0.32^{b}	0.3±0.11^{b}	0.2±0.02^{c}
Specific gravity	1.6±0.01^{d}	1.7±0.24^{c}	1.7±0.05^{b}	1.7±0.04^{a}
Total Solid (g/100 g)	19.0±0.07^{d}	20.3±0.05^{c}	21.1±0.21^{b}	22.5±0.02^{a}
SNF (g/100 g)	7.2±0.17^{c}	9.1±0.21^{b}	10.3±0.13^{a}	10.3±0.3^{a}

Values are expressed as mean ± standard deviation from triplicate analyses: Means sharing the same superscripts within a row are not significantly different ($p > 0.05$)

Key:
PCCNF: Plain Coconut Chocolate Non-Fortified drink
PCCF: Plain Coconut Chocolate Fortified drink
SCCNF: Sweetened Coconut Chocolate Non-Fortified drink
SCCF: Sweetened Coconut Chocolate Fortified drink

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RESULTS AND DISCUSSION

Physicochemical characteristics of fortified and non-fortified chocolate beverages

The physicochemical attributes of the beverage samples formulated with cocoa powder and coconut milk are shown in Table 2.

Physicochemical Quality Parameters of fortified Coconut Milk Chocolate beverages

pH and TTA of Formulated Sample

The pH values of the samples ranged from 6.54 to 6.72, while the total titratable acidity (TTA) varied from 0.35% lactic acid in sample PCCNF to 0.23% in SCCF. A significant variation (< 0.05) was observed among the drinks. Cocoa powder increased, leading to higher pH values and lower TTA values, indicating an inverse relationship between pH and TTA across the formulated samples. The chocolate drinks showed slightly acidic pH levels, which complied with the specification of ≥ 5.9 for coconut milk (Codex Alimentarius Commission 2022). The TTA values were consistent with Codex Standards for milk-based drinks and comparable to the findings for aqueous beverages made from moringa seeds and tiger nut (0.62–0.66% TTA) (Ashaver *et al.*, 2023). pH, which measures hydrogen ion concentration on a scale of 0-14, is crucial for determining milk drinks' taste and shelf life. It indicates the acidity or alkalinity of a solution (Kliks *et al.*, 2019). TTA represents the overall acid concentration in a food system. Both pH and TTA are critical factors in assessing the quality, characteristics, and stability of fortified and non-fortified coconut milk-based chocolate drinks (Usman & Bolade, 2020).

Specific Gravity of Formulated Sample

The Relative density of the samples varied from 1.58 to 1.75 for PCCNF and SCCF, respectively, with a significant difference observed between the drinks ($p < 0.05$). An increase in cocoa powder and sugar concentration resulted in higher specific gravity values. These findings are comparable to the range of 1.643 - 1.892 reported by Ashaver *et al.* (2023) for beverages produced from moringa seeds and tiger nut. The alignment of results between these two studies suggests similarity in the density characteristics of the beverages, despite the difference in base ingredients. The specific gravity of the drinks was all >1; this means the drinks were denser than water (the reference liquid). Specific gravity, also known as relative density, is a measurement without units. It is defined as the ratio between a substance's density and the density of water under specified temperature and pressure conditions. This property provides insight into the relative weight of a substance compared to water, offering valuable information about its composition and concentration (Usman & Bolade, 2020).

Total Solid Content of Formulated Sample

The total solid content ranged between 18.98 and 22.52 g/100 g. The highest was recorded for the sample SCCF, and the lowest was from PCCNF. A significant difference was observed among the samples ($p < 0.05$). The total solids content observed in this study fell within the Codex Alimentarius Commission (2022). Benchmark for coconut-based beverages (12.7 – 25.3 g/100 g). These findings also align with Yakum's study on soybean and tigernut milk yogurt enriched with ginger powder, which reported values between 18.72 - 19.96 g/100 g (Yakum *et al*., 2022). Cocoa powder, containing 88-91% total solids, contributed significantly to the total solid content of the beverages, which was directly influenced by their dry matter composition. As cocoa powder concentrations increased, the overall solid content correspondingly rose. Total solids indicate the remaining dry material after water has been extracted (Amadou *et al*., 2017). This parameter functions as a quality metric, assisting in evaluating whether liquid food products have achieved proper concentration levels or have become excessively diluted (Bristone *et al*., 2018).

Solid Non-fat Content of Formulated Sample

The solid non-fat (SNF) content in the beverage samples varied from 7.23 to 10.32 g/100 g for samples PCCNF and SCCNF, showing statistically significant differences at $P<0.05$. The SNF values recorded in this research were consistent with the FDA standards, which require milk-based beverages to maintain at least 8.25 g/100 g of solid non-fat content (Food Code Service, 2013)

A positive correlation was noted between cocoa powder concentration and solid non-fat content in the samples. This trend can be attributed to the composition of cocoa powder, which has a higher fat content compared to sugar. When the fat content is subtracted from the total solids to calculate solid non-fat, samples with higher sugar concentrations naturally show lower solid non-fat values. This relationship between ingredients and solid non-fat content highlights the impact of formulation on the nutritional and compositional profile of fortified and non-fortified chocolate drinks (Yakum *et al*., 2022).

Proximate composition of fortified and non-fortified chocolate drinks

Table 3 presents the proximate composition analysis for a variety of drink samples. These samples were created using different blends of three key ingredients: cocoa powder, coconut milk, and sugar, each incorporated at different concentration levels.

Nutrient profile of Coconut Milk Chocolate Beverages

The nutritional profile of the formulated samples, both fortified and non-fortified, reveals some key differences in fat, carbohydrate, and energy content. These differences can be explained by the variations in formulation, particularly the concentration of ingredients like cocoa powder and sugar, as well as the inclusion of fortifying elements.

Fat Content: The fat content of the coconut chocolate drink samples ranged from 11.75 to 12.27 g/100 g, with a statistically significant difference between the non-

Table 3. Nutritional compositions of fortified and non-fortified chocolate beverages

Nutrient (g/100 g)	Sample			
	PCCNF	PCCF	SCCNF	SCCF
Moisture	81.0±0.01^{a}	79.7±0.02^{b}	78.9±0.01^{c}	77.5±0.04^{d}
Protein	3.7±0.07^{b}	3.6±0.03^{b}	4.0±0.05^{a}	3.9±0.62^{a}
Ash	0.8±0.02^{b}	1.0±0.01^{a}	0.9±0.01^{b}	1.2±0.00^{a}
Fiber	0.03±0.01^{cb}	0.05±0.01^{ab}	0.04±0.03^{ab}	0.06±0.00^{a}
Fat	11.6±0.03^{b}	12.3±0.03^{a}	11.8±0.02^{b}	12.3±0.01^{a}
Carbohydrate	4.8±0.01^{c}	4.8±0.02^{c}	5.6±0.01^{a}	5.6±0.01^{a}
Energy (kcal/100 g)	139.4±0.57^{c}	145.1±0.37^{a}	143.1±0.23^{b}	148.7±0.12^{a}

Values are expressed as mean ± standard deviation from triplicate analyses: Means sharing the same superscripts within a row are not significantly different ($p > 0.05$)

Key:
PCCNF: Plain Coconut Chocolate Non-Fortified drink
PCCF: Plain Coconut Chocolate Fortified drink
SCCNF: Sweetened Coconut Chocolate Non-Fortified drink
SCCF: Sweetened Coconut Chocolate Fortified drink

fortified (PCCNF) and fortified (SCCF) variants (P< 0.05). Importantly, the fat levels in both the PCCNF and SCCF samples met the Codex Alimentarius Commission (2022) minimum standard of 10 g fat per 100 g for coconut milk-based products. However, overconsumption of foods rich in fats and sugar products can pose health risks (Codex Alimentarius Commission, 2022). An increase in cocoa powder led to higher fat levels, primarily due to coconut's naturally high fat content. Coconut fats are composed mostly of short-chain carboxylic acids, along with mono- and polyunsaturated lipids, which are considered healthier compared to trans fats typically found in some other foods. This composition can be beneficial, as these fats are less likely to contribute to cardiovascular disease (Giri & Mangaraj, 2012).

Carbohydrate Content: The carbohydrate levels in the beverage samples varied from 4.82 to 5.58 g/100 g, which aligns with findings from similar plant-based drinks such as yogurt-like beverages (Bristone *et al*., 2018). Higher concentrations of cocoa powder and sugar resulted in higher carbohydrate content. The relatively low carbohydrate levels in these samples suggest that these drinks are not a significant source of carbohydrates. Instead, these beverages are more often consumed as snacks or desserts, rather than primary nutritional sources, providing hydration, refreshment, and, in some cases, potential probiotic benefits (Priyanka Aswal, 2012).

Energy Content: The caloric value of the coconut chocolate beverages varied from 139.4 to 148.7 kcal per 100 g, showing statistically significant differences between the PCCNF and SCCF samples (P<0.05). The increase in energy content was directly associated with higher fat concentrations in the samples. The ener gy values of these drinks were lower than those found in date-coconut drinks, which ranged from 325.2 to 332.1 kcal per 100 g, as reported by Belewu *et al*. (2014). This discrepancy could be ascribed to differences in the processing techniques and dilution factors in the studies. Despite these variations, the energy content of these coconut-based drinks positions them as a moderate energy source within the context of snacks or indulgent beverages.

Physicochemical Quality of Formulated Drinks

Moisture Content: Moisture levels in the coconut-chocolate drinks ranged from 77.5 to 81.0 g/100 g for both PCCNF (Plain Coconut Chocolate Non-Fortified) and SCCF (Sweetened Coconut Chocolate Fortified), with a significant difference (P<0.05) observed. A decrease in moisture occurred as cocoa powder and sugar concentrations increased. Compared to soy yogurt values (86.34–94.12 g/100 g), Akusu & Wordu (2017), the drinks had lower moisture, likely due to the low moisture content of cocoa powder (<10%) and fortifying ingredients increasing dry matter. Lower moisture generally improves shelf life by reducing the risk of spoilage and microbial growth (Khan *et al*., 2016).

Ash Content: Ash content ranged from 0.83 to 0.98 g/100 g, with significant differences (P<0.05). Higher cocoa powder levels resulted in increased ash. This exceeded previously reported values for dairy and spiced yogurt drinks (0.67–0.76 g/100 g), likely due to fortification with KI (0.15 mg), $FeSO_4$ (2.0 mg), and retinol palmitate (1.6 mg/100 g). Cocoa powder's high ash content (~8 g/100 g), which enhanced the mineral content (González-Tenorio *et al*., 2012)

Fiber Content: Crude fiber ranged from 0.03 to 0.06 g/100 g, with significant differences (P<0.05). Fiber increased with cocoa powder concentration. Though lower than values found in tiger nut milk (0.24–0.33 g/100 g), Gambo & Da'u (2014), the drinks still offer some dietary fiber, important for digestive health (Ilesanmi Adeyeye, 2016).

Nutritional Enhancement of Formulated Drinks

Protein Content: Protein levels ranged from 3.6 to 4.0 g/100 g, increasing with higher cocoa powder. These were slightly lower than plant-based yogurt-like drinks (3.73–4.82 g/100 g), Yakum *et al*. (2022), likely due to coconut milk's lower protein profile compared to soy milk, which contains essential amino acids (Hymavathi *et al*., 2020; Kaushal *et al*., 2017).

Fat Content: Fat content ranged from 11.75 to 12.27 g/100 g, with significant differences (P<0.05). Higher cocoa powder increased fat, while sugar addition reduced it. Coconut's naturally high fat content, mainly short-chain, polyunsaturated, and monounsaturated fats, is considered beneficial, potentially reducing cardiovascular risk (Giri & Mangaraj, 2012). All samples met the Codex Alimentarius (2022) standard of ≥10 g fat/100 g for coconut milk products.

Carbohydrate Content: Carbohydrate content ranged from 4.82 to 5.58 g/100 g, increasing with cocoa and sugar concentrations. These values are consistent with other plant-based yogurt-like drinks (3.77–9.27 g/100 g), Bristone *et al*. (2018). While not a major carbohydrate source, these beverages serve primarily as refreshing snacks or probiotic carriers (Priyanka Aswal, 2012).

Fortification Impact on the Formulated Drinks

Ash Content: Ash content ranged from 0.83 to 0.98 g/100 g, with significant differences (P<0.05). Higher cocoa powder levels resulted in increased ash. This exceeded previously reported values for dairy and spiced yogurt drinks (0.67–0.76 g/100 g), likely due to Fortification with KI (0.15 mg), $FeSO_4$ (2.0 mg), and Retinol palmitate (1.6 mg/100 g). Cocoa powder's high ash content (~8 g/100 g), which enhanced the mineral content (González-Tenorio *et al*., 2012).

Energy Content: Energy ranged from 139.4 to 148.7 kcal/100 g, with notable differences (P<0.05). Energy increased alongside fat content. These values were lower than those in date-coconut drinks (325.2–332.1 kcal), Belewu *et al*., (2014), likely due to differences in dilution and formulation.

Vitamin levels in fortified and non-fortified coconut milk chocolate beverages

Table 4 displays the vitamin content of the beverage samples.

Table 4. Vitamin profiles of fortified and non-fortified chocolate beverages

Vitamin	Sample			
(mg/100 g)	PCCNF	PCCF	SCCNF	SCCF
Pro vit A	1.1±0.06^{b}	2.5±0.9^{a}	1.2±0.01^{b}	2.6±0.01^{a}
B_1	0.18±0.05^{b}	0.17±0.07^{b}	0.21±0.05^{a}	0.20±0.03^{a}
B_2	0.09±0.03^{b}	0.08±0.02^{b}	0.12±0.02^{a}	0.11±0.05^{a}
C	3.5±0.05^{b}	3.4±0.03^{b}	5.8±0.05^{a}	5.7±0.03^{a}
K	0.7±0.05^{b}	0.6±0.03^{b}	1.2±0.06^{a}	1.1±0.03^{a}

Values are expressed as mean ± standard deviation from triplicate analyses: Means sharing the same superscripts within a row are not significantly different (p > 0.05)

Key:
PCCNF: Plain Coconut Chocolate Non-Fortified drink
PCCF: Plain Coconut Chocolate Fortified drink
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Influence of Fortification and Cocoa Powder on the Vitamin Profile of the Drinks

The vitamin composition of the chocolate drinks was significantly influenced by both fortification and the concentration of cocoa powder, as illustrated in Table 4. Fortified and non-fortified drinks showed varying levels of key vitamins, with fortification and increased cocoa powder concentrations both contributing to enhanced nutritional value.

Pro-vitamin A content ranged from 1.081 mg/100 g in PCCNF (non-fortified) to 2.569 mg/100 g in SCCF (fortified), indicating a notable increase due to fortification. The levels of provitamin A in the fortified samples were comparable to those found in similar fortified beverages, such as tiger nut and moringa milk blends (Ashaver *et al*., 2023). This vitamin is vital for maintaining good vision, skin health, immune function, and preventing certain eye diseases, especially in children and the elderly. Fortification contributed significantly to the provitamin A content, enhancing the drink's antioxidant properties.

Vitamin B1 (Thiamine) levels ranged from 0.081 mg/100 g in PCCNF to 0.205 mg/100 g in SCCF, with a significant difference observed between samples. The vitamin B_1 content increased with the concentration of cocoa powder, as cocoa is naturally rich in this nutrient. The higher concentrations of cocoa powder in the drinks led to elevated thiamine levels, though the amounts remained below the Recommended Daily Allowance (RDA) for adults (McClements *et al*., 2019). Vitamin B_1, essential for glucose metabolism, nerve function, and overall heart health, added nutritional value to the drinks despite not meeting the full daily requirement (Yadav *et al*., 2015).

Vitamin B_2 (Riboflavin) levels ranged from 0.061 mg/100 g in PCCNF to 0.114 mg/100 g in SCCF. The vitamin B_2 content also increased with higher concentrations of cocoa powder, showing that cocoa contributes to riboflavin levels in these drinks. However, the levels remained below the RDA, similar to those found in other plant-based drinks (McClements *et al*., 2019). Vitamin B_2 plays a crucial role in cellular respiration, and its stability under heat treatments makes it an important nutrient in processed beverages (Yadav *et al*., 2015).

2022). Vitamin K is essential for blood clotting, bone health, and calcium regulation, adding value to the drinks' overall vitamin profile (Donovan & Shamir, 2014).

Mineral Analysis of Fortified and Non-Fortified Coconut-Chocolate Drinks

Table 5 presents the mineral profile of the drink samples, focusing on selected minerals.

Table 5. Mineral profile of fortified and non-fortified coconut milk chocolate drinks

Minerals (mg/100 g)	Sample			
	PCCNF	PCCF	SCCNF	SCCF
Ca	21.5±0.6[b]	21.4±0.3[b]	27.1±0.8[a]	27.0±0.8[a]
Na	16.2±0.2[b]	16.1±0.6[b]	18.1±0.6[a]	18.0±0.3[a]
Mg	54.7±0.5[b]	54.6±0.1[b]	72.7±0.3[a]	72.5±0.2[a]
K	250±2.5[b]	253±1.4[b]	260±3.1[a]	264±2.0[a]
Zn	2.5±0.20[b]	2.4±0.1[b]	3.4±0.3[a]	3.2±0.2[a]
Fe	2.0±0.3[b]	4.0±0.5[a]	2.3±0.2[b]	4.3±0.2[a]
I	0.2±0.01[c]	0.4±0.1[a]	0.2±0.01[c]	0.4±0.1[a]

Values are expressed as mean ± standard deviation from triplicate analyses: Means sharing the same superscripts within a row are not significantly different (p > 0.05)

Key:
PCCNF: Plain Coconut Chocolate Non-Fortified drink
PCCF: Plain Coconut Chocolate Fortified drink
SCCNF: Sweetened Coconut Chocolate Non-Fortified drink
SCCF: Sweetened Coconut Chocolate Fortified drink

Vitamin C (Ascorbic acid) content ranged from 2.981 mg/100 g in PCCNF to 5.751 mg/100 g in SCCF. The concentration of vitamin C increased with higher cocoa powder levels, further enriched by coconut milk's naturally higher vitamin C content compared to other plant-based drinks like soybean milk. Though the vitamin C content in the drinks was lower than the RDA (45-120 mg per day), it still contributed to immune system function, tissue repair, and wound healing (Kaushal *et al*., 2017). The higher concentrations of cocoa powder played a significant role in boosting the vitamin C levels (McClements *et al*., 2019).

***Vitamin* K** levels ranged from 0.141 mg/100 g in PCCNF to 1.137 mg/100 g in SCCF, with a significant difference between samples. The presence of vitamin K in these drinks increased with higher cocoa powder concentrations, emphasizing cocoa's contribution to vitamin K levels. Despite falling below the daily nutritional requirement for vitamin K (120 mg for adult males), the levels in the drinks were still nutritionally significant (Tulashie *et al*.,

Influence of Fortification on the Mineral Content of Chocolate Drinks

Iron (Fe) Content: Fortification with FeSO4 led to a noticeable increase in the iron content in the SCCF sample (4.10 mg/100 g) compared to PCCNF (1.96 mg/100 g). This aligns with (Usman & Bolade, 2020), who reported similar trends in fortified plant-based milk. Iron is crucial for hemoglobin production, energy metabolism, and immune function, though the levels in this study still fall short of the RDA (8-18 mg per day) (El-Bialy *et al*., 2020). Despite this, the fortification effectively improved the iron content, making these drinks a better source of iron than non-fortified options.

Iodine (I) Content: The iodine content was also higher in the fortified drink (SCCF) compared to the non-fortified sample (PCCNF), with values ranging from 0.16 to 0.38 mg/100 g. The fortification with potassium iodide (KI) contributed to this increase. Iodine is essential for thyroid hormone production, which regulates metabolism, bone, and brain development. The iodine content in the fortified samples meets the Nutritional guideline value for expectant mothers and infants, suggesting these drinks could be an adequate source of iodine for these populations (Food fortification Regulations, 2021).

Potassium (K) Content: Potassium content ranged from 250 to 264 mg/100 g, with the fortified sample (SCCF) showing the highest value. The potassium content in the chocolate drinks is slightly higher than the reported range for yogurt (146-264 mg/100 g) by McClements *et al.* (2019). This rise in potassium levels can be due to the cocoa powder, which contains significant amounts of potassium. Potassium is important for regulating fluid balance, muscle contractions, and nerve signals, and a potassium-rich diet may help reduce blood pressure and prevent kidney stones. However, the potassium content in these drinks is still below the RDA of 3500-4700 mg per day (Embark *et al*, 2018).

Influence of Cocoa Powder Concentration on the Mineral Content of Chocolate Drinks

Calcium (Ca) Content: The calcium levels in the drinks varied significantly (P<0.05) across samples, with the lowest calcium content (21.44 mg/100g) observed in the fortified plain coconut milk chocolate drink (PCCF) and the highest (27.05 mg/100g) in the sweetened non-fortified coconut milk chocolate drink (SCCNF). A clear trend emerged, showing that the calcium content increased with the concentration of cocoa powder in the formulations. This suggests that cocoa powder is a significant source of calcium in the drinks, with higher concentrations of cocoa powder leading to elevated calcium levels. While fortification and sweetening may also contribute to the overall calcium content, the increase in cocoa powder concentration plays a primary role in enhancing calcium levels in the beverages.

Sodium (Na) Content: The sodium content ranged from 16.13 mg/100 g (PCCNF) to 17.99 mg/100 g (SCCF), with a significant difference (P<0.05) between the non-fortified and fortified samples. As cocoa powder naturally contains sodium (235-245 mg/100 g), higher cocoa concentrations in the samples likely contributed to increased sodium levels. However, the sodium values are still much lower than those found in yogurt (111.1 - 111.4 mg/100 g), Amadou *et al*. (2020), with the sodium content in both samples being far below the recommended daily intake of 2300-3400 mg (Usman & Bolade, 2020). Sodium is crucial for fluid balance and blood pressure regulation.

Magnesium (Mg) Content: Magnesium content ranged from 54.57 to 72.64 mg/100 g, with the highest value recorded in the fortified sample (SCCF). The increase in magnesium content is likely due to the presence of cocoa powder, which is rich in magnesium (51-56.3 mg/100 g). This elevated magnesium content is higher than the 20-49 mg/100 g range typically reported for plant-based milk (Mazumder & Hongsprabhas, 2016). Magnesium plays key roles in energy metabolism, nerve function, and bone strength, although the values fall short of the RDA of 200-400.1 mg per day (Oladele & Aina, 2007). Nevertheless, the cocoa powder fortification makes these drinks a good supplementary source of magnesium.

Zinc (Zn) Content: The zinc content ranged from 1.137 to 3.380 mg/100 g, with higher values recorded in the fortified sample (SCCF). An increase in cocoa powder concentration led to higher zinc levels, aligning with previous studies that indicated plants generally have higher zinc content than animal-based sources (Amadou *et al*., 2020). Zinc serves an essential function in immune system health, tissue repair, and carbohydrate metabolism. However, the levels observed in these drinks are still below the Required Dietary Allowance (RDA) of 8-11 mg per day, indicating the need for additional sources of zinc in the diet (Oladele & Aina, 2007).

CONCLUSION

In conclusion, this study successfully developed coconut milk chocolate drinks that could serve as effective vehicles for micronutrient fortification. By incorporating locally available coconut and cocoa resources, the drinks were not only nutrient-dense but also addressed pressing issues of protein-energy malnutrition and micronutrient deficiencies, particularly among children and pregnant women in sub-Saharan Africa. The findings highlight the significant impact of fortification on improving the micronutrient profile of the drinks, with increased levels of potassium, iron, iodine, and provitamin A in the fortified formulations (PCCF and SCCF) compared to the non-fortified versions. Moreover, the improvements in protein and carbohydrate content through the addition of cocoa powder and fortificants further contribute to the nutritional value of the drinks. These results demonstrate that coconut milk chocolate drinks, when fortified with iodine, iron, and provitamin A, can play a crucial role in addressing nutrition deficiencies and can be integrated into local intervention programs aimed at enhancing public health in resource-limited regions.

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