Sensory and rheological properties of fortified coconut milk based chocolate drink as influenced by cocoa powder and sugar levels

ABSTRACT

Purpose: The sensory and rheological properties of fortified drinks produced from coconut milk, cocoa powder and sugar was evaluated.

Methodology: Drinks samples were formulated with different concentration of coconut milk, cocoa powder and sugar levels. Samples incudes: K1 (Coconut milk 100 %), K2 (Coconut milk 99.8 % cocoa powder 0.2 %), K3 (Coconut milk 99.6 %, cocoa powder 0.4%), K4 (Coconut milk 98 %, sugar 2%), K5 (Coconut milk 97.8 %, cocoa powder 0.2%, sugar 2%), K6 (Coconut milk 97.6 %, cocoa powder 0.4%, sugar 2%), K7 (Coconut milk 96 %, sugar 4%), K8 (Coconut milk 95.8 %, cocoa powder 0.2%, sugar 4%), K9 (Coconut milk 95.6 %, cocoa powder 0.4%, sugar 4%). The samples were produced and subjected to physicochemical, proximate, vitamins and minerals analysis using standard methods.

Results: Sensory evaluation; appearance from 8.13(K9) to 7.00 (K2), Aroma from 7.93 (K9) to 6.53 (K1), Mouth feel from 7.83 (K8) to 6.63 (K1) and 6.63 (K3), Taste from 7.90(K9) to 6.27 (K1) and General Acceptability from 8.30 (K9) to 6.40 (K3).The rheological parameters using the power law; consistency index (m) 0.003 to 0.19 (Ns^n/m^2), flow behavior index (n) n<1 for all drink samples.For the Arrhenius model, µo (frequency factor) ranged from 1.9 x10 $^{-5}$ to 5.1 x 10 $^{-8}$. Ea (activation energy) ranged from 15.55 to 30.70 KJ/mol. The r squared for both power law model and Arrhenius model, ranges from 0.825 to 0.99 that is approximately 1. Cocoa powder and sugar levels improved sensory profile. The flow behaviour indices (n) of drinks were all less than 1(n < 1) this implies pseudoplastic flow behaviour for drinks samples.

1.0 Introduction

Coconutis the fruit of the coconut palm (*Cocos nucifera L.*). It has a hard shell, edible white flesh and clear liquid (water), it is often used for its water, milk, oil, and tasty meat (Abdullahi & Yakubu, 2014).Coconut milkis an opaque, white liquid with a rich taste extracted from the meat of a mature coconut. Coconut contains sugar, dietary fiber, proteins, fat, antioxidants, vitamins and minerals which is essential for human nutrition (Belewu et al., 2014).

Comment [AB1]: This study investigated the sensory and rheological properties of fortified drinks made from coconut milk, cocoa powder, and sugar.

Comment [AB2]: They have a hard shell, edible white flesh, and clear liquid (water). Coconuts are often used for their water, milk, oil, and tasty meat (Abdullahi & Yakubu, 2014).

Comment [AB3]: Coconuts

Comment [AB4]: flesh

Coconut milk is one of the most popular plant based milk alternatives to replace animal milk. The increasing demand for coconut milk worldwide is contributed by increasing veganism, increasing demand for lactose-free milk, and the discovery of the health benefits of coconut milk fats and vitamins (Matin et al., 2020).

Cocoa powder isderived from cocoa beans, seed of the cacao tree (*Theobroma cacao*), and the key ingredient in producing chocolate and chocolate drinks.A good source of high quality protein, vitamins A & D, B-12, riboflavin, and minerals (calcium phosphorus, magnesium, and zinc) (Hanks et al., 2014).Chocolate drinks are one of the cocoa-derived products that are in high demand among consumers

Food fortificationis the practice of deliberately increasing the content of one or more micronutrients (vitamins and minerals) in a food or condiment to improve the nutritional quality of the food supply and provide a public health benefit with minimal risk to health (Regulations, 2021)

Many consumers are interested in reducing their consumption of animal products such as cow milk, goat milk etc due to health, environmental and ethical issues. Developing plant based alternatives such as coconut milk based chocolate drink could serve as an alternative with better nutritional profile for people with lactose intolerance, cow milk allergy and vegetarians.Producing a milk drink from coconut milk and cocoa powder will produce another variety of drink, thus diversification of food production(Aribah et al., 2020).

Most beverages available in the markets are energy drinks with high sugar content and little nutritional value which is a concern to diabetes patients and people with heart diseases. Producing a drink from coconut milk and cocoa powder with low sugar could be a good source of nourishment thus improved nutritional status(Putri & Sukma, 2021).

Also cow milk is becoming increasingly expensive, using coconut milk and cocoa powder as alternative could be of advantage since they are locally cultivated, readily available and affordable in the local markets thus reduce post-harvest loses of crop.

Most flavourant and colourants used in the industrial production of drink are synthetic. The use of natural cocoa powder from plant sources could be more beneficial to the consumer's health because they are sources of minerals, fibre and vitamins and bioactive compounds(Klis et al., 2023). The combination of coconut milk and cocoa powder could improve the health

Comment [AB5]: Most flavorings and colorants

Comment [AB6]: The use of **natural cocoa powder**, a plant source, **could be more beneficial** to consumers' health because **it** is a source of minerals, fiber, vitamins, and bioactive compounds (Klis et al., 2023).

benefits of milk drink thus improving the nutritional status and rendering it more functional non-alcoholic milk drink.

2.0 MATERIAL AND METHODS

The material used for the processing of drinksamples includes, coconut fruits, cocoa beans, sugar. These were purchased from modern market Makurdi Benue state Nigeria for processing.

2.1 Preparation of cocoa powder

Cocoa powder was produced from cocoa beans as shown on figure 1. The cocoa beans was sorted and cleaned to removed dirt and foreign particles. The beans was roasted at a temperature of 150-190 °Cfor 5 to 15 min. (Setiadi et al., 2021) . The roast beans was peeled and the shells removed by winnowing. The seeds was then crushed and ground for oil extraction. The cocoa mass / liquor was pressed using a hydraulic press to extract the cocoa butter. The mass of the roast beans after the cocoa butter was extracted was dried for the production of cocoa butter. As the pressing does not remove all the cocoa butter, so the particles will remain coated with a thin layer of cocoa butter with fat content of cocoa powder varies from 8% to 26%. The cake was then further dried at 60 °C for 24 h and then crushed and grind finely to very small particle sizes. The powder was then sieved with a sieve of particle size < 0.5 mm to obtain a fine powder. The cocoa powder was packaged and stored for further processing to chocolate drink.

2.2 Preparation of coconut milk

Coconut milk was prepared from grated meat or endosperm by mechanically expressing the milk (figure 2).

The husk of matured coconut used was removed, exposing the hard shell. The shell of the coconut was removed manually by cracking the shell open with a knife or hitting it against a hard surface. Paring was done by scraping away of the brown skin attached to the coconut

Comment [AB7]: thus improving

Comment [AB8]: Cocoa powder is produced from cocoa beans, as shown in Figure 1. The cocoa beans are first sorted and cleaned to remove dirt and foreign particles. Then, the beans are roasted at a temperature of 150-190 °C for 5 to 15 minutes (Setiadi et al., 2021).

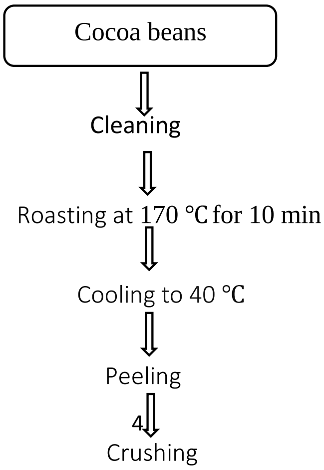
Comment [AB9]: The roasted beans are peeled, and the shells are removed by winnowing. The seeds are then crushed and ground for oil extraction. The cocoa mass, also called cocoa liquor, is pressed using a hydraulic press to extract the cocoa butter. The remaining mass after the cocoa butter is extracted is dried and used for cocoa powder production. Since pressing doesn't remove all the cocoa butter, the particles remain coated with a thin layer, resulting in a fat content of cocoa powder varying from 8% to 26%. The cake is then further dried at 60°C for 24 hours. After drying, it's crushed and ground finely into very small particles. The powder is then sieved through a sieve with a mesh size of less than 0.5 mm to obtain a fine cocoa powder. Finally, the cocoa powder is packaged and stored for further processing, such as making chocolate drinks.

Comment [AB10]: Coconut milk is prepared from grated coconut meat (endosperm) by mechanically expressing the milk, as shown in Figure 2.

meat to give white coconut meat using a knife. The paired coconut was rinsed with clean water to remove specks of dirt and impurities attached to the coconut meat. The clean coconut meat was cut into smaller sizes with the use of a knife. The coconut cut was pulverized/ground into smaller particles using a blender with added potable water. Milk was extracted by pressing the ground coconut to extract the milk. A cheesecloth was used to squeeze out milk from the blended coconut. The extracted milk was filtered to remove any form of sediments. Extracted coconut milk was pasteurized at 70°C for 15min. Cooled, filled into plastics bottles, sealed and labeled and stored under refrigerated conditions (2-4) ℃ (Adhikari, 2018).

Comment [AB11]: A mature coconut first has its husk removed, exposing the hard shell underneath. This shell can then be cracked open manually using a knife or by hitting it against a hard surface. Finally, the brown skin attached to the coconut meat is scraped away with a knife to reveal the white flesh.

Comment [AB12]: The paragraph is grammatically correct with accurate conjugation, but there's room for improvement in clarity and flow. Here's a revised version:
After paring, the coconut flesh is rinsed with clean water to remove any remaining dirt or impurities. The clean flesh is then cut into smaller pieces using a knife. These pieces are pulverized or ground into finer particles using a blender with added potable water. To extract the milk, the ground coconut is pressed, squeezing out the liquid. A cheesecloth helps separate the milk from the coconut solids further. The extracted milk is then filtered to remove any sediment. Finally, the coconut milk undergoes pasteurization at 70°C for 15 minutes. Once cooled, it's filled into plastic bottles, sealed, labeled, and stored under refrigeration (2-4°C) (Adhikari, 2018).



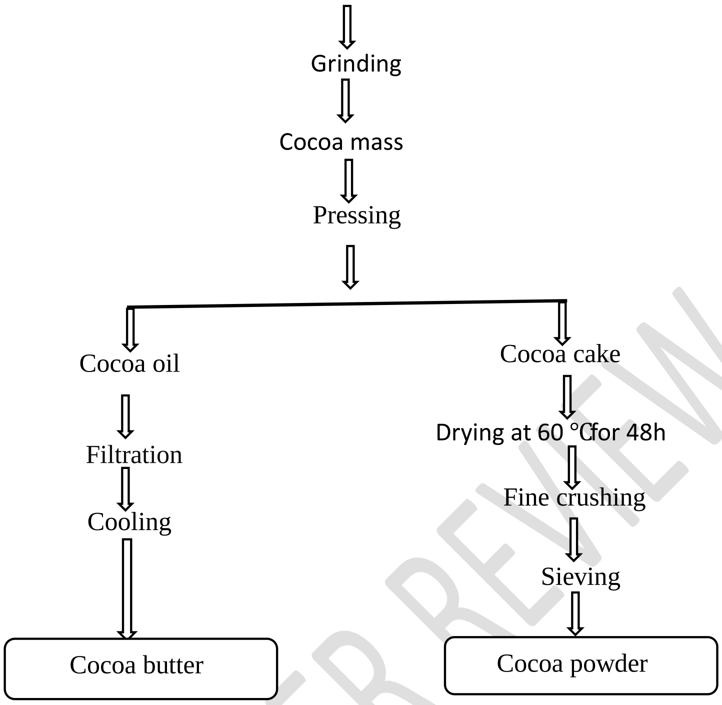
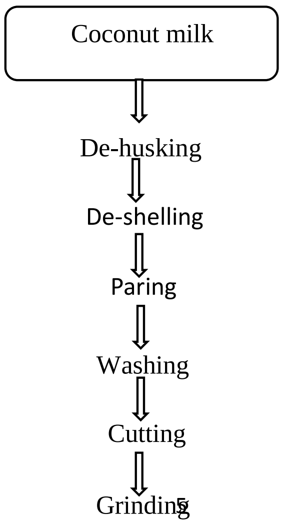


Figure 1: Flow chart for the production of cocoa powder



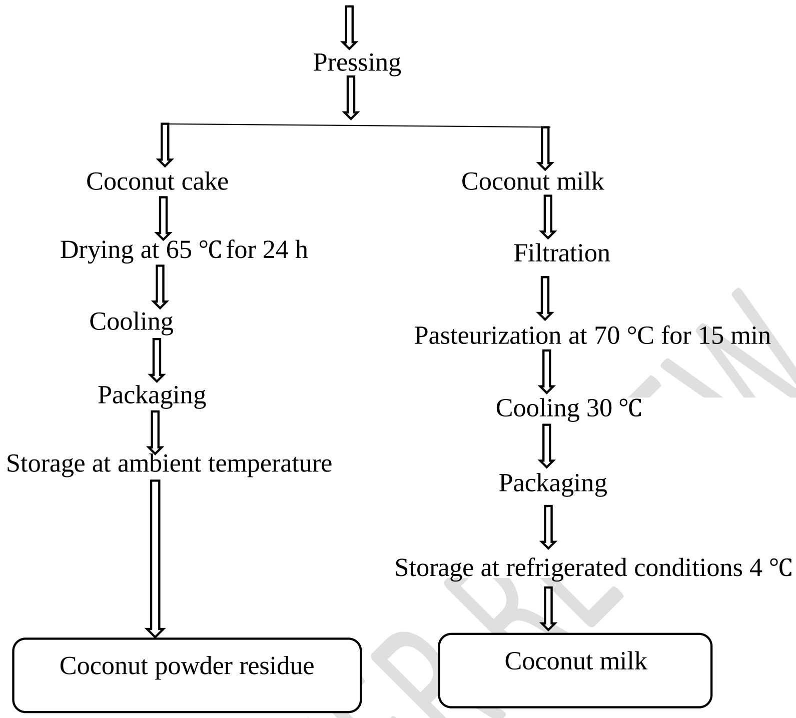


Figure 2: Flow chart for the production of coconut milk

2.3 Chocolate Drink formulation and sampling

Drink samples was formulated by varying the proportions of coconut milk, cocoa powder and sugarusing 1x3x3 experimental design comprising 3 levels of cocoa powder (0 %, 0.2 %, 0.4 %) and 3 levels of sugar (0 %, 2 %, and 4 %) which yielded 9 experimental samples, where 100 % coconut milk was used as control. The drinks were subjected to nutritional quality analysis using standard methods (AOAC, 2012).

Comment [AB13]: were formulated

Comment [AB14]: changed to "A 3 x 3 x 1 experimental design was used

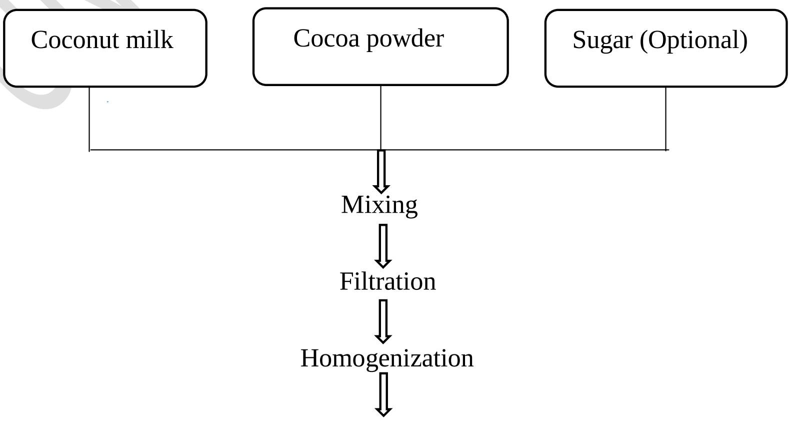
Comment [AB15]: This yielded a total of 9 experimental samples"

Comment [AB16]: with 100% coconut milk used as a control

2.4 Production of coconut-based chocolate drink

Coconut based chocolate drink was produce by blending coconut milk and cocoa powder in different proportions to obtained the formulated sample that was subjected to analysis as seen on figure 3. Coconut milk and cocoa powder was mixed during which sugar (Optional) was added. The blend was filter to get rid of any foreign particles that might have gained entering during the mixing. The mixture is homogenized to have uniform distribution of particles and also to achieve a uniform consistency. The drink was then be Pasteurization at the temperature of 85 -90 ℃ for 3-5min to get rid of pathogenic and food spoilage microorganisms. The drink is then be Cooled to 10-15 and packaged in air tight containers for storage.

Comment [AB17]: Coconut-based chocolate drinks were produced by blending coconut milk and cocoa powder in various proportions to create the formulated samples analyzed in Figure 3. The coconut milk and cocoa powder were mixed, with optional sugar added during this step. The blend was then filtered to remove any foreign particles that might have entered during mixing. To achieve a uniform distribution of particles and consistency, the mixture was homogenized. Finally, the drink underwent pasteurization at 85-90°C for 3-5 minutes to eliminate pathogenic and food spoilage microorganisms. After cooling to 10-15°C, the drink was packaged in airtight containers for storage.



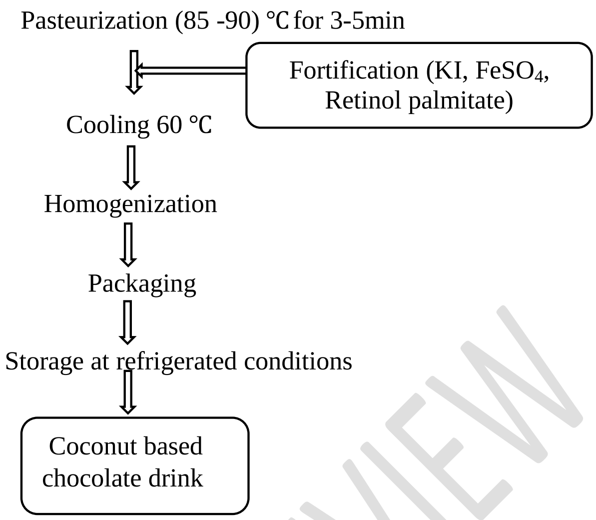


Figure 3: Flow chart for the production of coconut-based chocolate drink
Source: (Abadl et al., 2023)

2.4.0 Analysis

2.4.1 Rheological analysis of drink samples

Apparent viscosity (Shear stress) was obtained using a Brookfield digital viscometer (Model DV-II, Spindle-0, Canada), using standard methods(Hymavathi et al., 2020).The experimental measurements was performed in triplicate using spindle 61 at different shear rates (5, 10, 20, 50 and 100 rpm) and at different temperatures, (10, 20, 30, 40 ℃). The temperatures was defined in order to provide rheological data of the products aiming at a possible application on an industrial scale, based on its relevance in sizing of equipment and piping (Silva et al., 2020). Apparent viscosity versus shear rate data was fitted with the power law model and Arrhenius equation as follows

2.4.1.1 Power law model

The rheological data were analyzed using Power law

$$\mu = m\gamma^{n-1} \quad (1)$$

Linearizing gives

$$\mathbf{ln\mu = \mathit{ln}\, m + (n-1)\mathit{ln}\,\gamma} \quad (2)$$

Where,

μ = viscosity or shear stress of drink samples (Ns/M^2)

γ = Share rate (rpm)

M = consistency index

n = flow behavior index

Plotting a graph of ln μ versus ln γ (ln of viscosity versus ln of shear rate) gives slope as n-1 and intercept as ln m

2.4.1.2Arrhenuis equation

$$\mu = \mu o. e - \frac{Ea}{RT} \quad (3)$$

Linearizing this equation gives (3)

$$ln\mu = ln\mu o - \frac{Ea}{R}\left(\frac{1}{T}\right) \quad (4)$$

Where,

μ = viscosity or shear stress of drink samples (Ns/M^2)

μ_o = frequency factor (Arrhenius constant)

e=The base of natural logarithm (Eulers number)

Ea= Activation energy (KJ/mol)

R= The universal gas constant 0.008314KJ/mol℃

T= absolute temperature associated with the reaction

Plotting a graph of ln μ versus $\frac{1}{T}$ (ln of viscosity versus 1/temperature) gives

Slope = $-\frac{Ea}{R}$ intercept = $ln\mu o$

2.4.2 Sensory evaluation of drink samples

Sensory evaluation of the drink samples was carried out using 30 panelists. Panelists were required to evaluate the appearance,aroma, taste, mouth feel and general acceptability of the drink samples using a 9-point Hedonic scale with 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely. Each panelist was provided with 9 different samples of drink at 10-12 °C in disposable plastic cups with coded labels. The panelist was required to taste the drink samples and fill the necessary information on the questionnaire. A cup of potable water was also provide to rinse the mouth after the analysis of each sample (Amadou et al., 2020; Perna et al., 2014; Steve & Olufemi, 2019).

Comment [AB18]: Sensory evaluation of the drink samples was conducted using 30 panelists. The panelists were required to evaluate the appearance, aroma, taste, mouthfeel, and overall acceptability of the drink samples using a 9-point hedonic scale, where 1 = dislike extremely, and 9 = like extremely. Each panelist received 9 different drink samples at 10-12°C presented in disposable plastic cups with coded labels. Panelists tasted the samples and filled out a questionnaire with the required information. A cup of potable water was also provided to rinse their mouths between samples (Amadou et al., 2020; Perna et al., 2014; Steve & Olufemi, 2019).

2.4.2 Statistical analysis

Data were subjected to analysis of variance (one-way ANOVA) where it was appropriate and means separated by Duncan's Multiple Range test (DMRT) at 0.05 level of significance. Using the statistical package for social sciences SPSS version 28.(Matin et al., 2020)

3.0 Results and discussion

3.1 Sensory properties of fortified coconut milk based chocolate drinks

The mean sensory scores of fortified coconut milk based chocolate is presented in table 1

The appearance scores for fortified drinks samples ranged from 7.77 (like very much) to 8.70 (like extremely) for coconut milk 99.8 % cocoa powder 0.2 % and Coconut milk 95.6 %, cocoa powder 0.4%, sugar 4% with significant difference at $p<0.05$.

Aroma of fortified drink samples ranged from 7.40 (like moderately) to 8.57 (like for samples coconut milk 99.8 % cocoa powder 0.2 % and Coconut milk 95.8 %, cocoa powder 0.2%, sugar 4% with significant difference at $p<0.05$.

Mouth feel ranged from 7.20 (like moderately) to 8.37 (like very much) for Coconut milk 99.6 %, cocoa powder 0.4% and Coconut milk 95.6 %, cocoa powder 0.4%, sugar 4% with significant difference at $p<0.05$.

Taste of fortified drinks samples ranged from 7.20 (like moderately) to 8.37 (like very much) for samples coconut milk 99.6 %, cocoa powder 0.4% and Coconut milk 95.6 %, cocoa powder 0.4%, sugar 4% with significant difference at $p<0.05$

Overall acceptability of fortified drink samples ranged from 7.50 (like very much) to 8.40 (like very much) for samples coconut milk 99.6 %, cocoa powder 0.4% and coconut milk 95.6 %, cocoa powder 0.4%, sugar 4% with significant difference at $p<0.05$

Table 1: Mean sensory scores for fortified coconut milk based chocolate drinks

Samples code	Appearance	Aroma	Mouth feel	Taste	Overall acceptability
524	$7.87^{bc} \pm 1.22$	$7.40^{d} \pm 0.72$	$7.63^{c} \pm 0.85$	$7.37^{b} \pm 0.96$	$7.70^{bc} \pm 0.92$
382	$7.77^{c} \pm 0.86$	$7.47^{d} \pm 1.19$	$7.53^{c} \pm 0.89$	$7.37^{b} \pm 0.99$	$7.77^{bc} \pm 0.89$
461	$7.93^{bc} \pm 0.83$	$7.63^{cd} \pm 0.96$	$7.50^{c} \pm 0.68$	$7.20^{b} \pm 1.06$	$7.50^{c} \pm 0.68$

365	8.03^{bc} ±1.13	8.03^{bc} ±0.96	8.07^{ab} ±0.78	8.13^{a} ±0.68	8.03^{ab} ±0.72
412	8.13^{bc} ± 0.73	8.00^{bc} ±0.78	7.90^{bc} ±0.76	8.03^{a}±0.85	8.03^{ab} ±0.93
354	8.23^{a} ±0.86	8.20^{a} ±0.99	7.83^{bc} ±0.75	7.97^{a} ±1.06	7.97^{ab} ±0.89
514	8.07^{bc} ± 0.91	7.97^{bc} ±0.85	8.03^{ab} ±0.63	8.00^{a} ±0.81	8.00^{ab} ±0.58
439	8.37^{a} ±0.62	8.57^{a} ± 0.86	8.43^{a} ±0.63	8.16^{a} ±0.79	8.37^{a} ±0.67
452	8.70^{a} ±0.54	8.37^{a} ±0.76	8.50^{a} ±0.66	8.37^{a}±0.79	8.40^{a} ±0.72

Mean values within the same column having the same letter are not significantly different at p> 0.05

Data are means of 30 panelists response on a scale of 9 =like extremely and 1= dislike extremely

Key

The samples code represent fortified drink produced from:

524: Coconut milk 100 %

382: Coconut milk 99.8 % cocoa powder 0.2 %

461: Coconut milk 99.6 %, cocoa powder 0.4%

365: Coconut milk 98 %, sugar 2%

412: Coconut milk 97.8 %, cocoa powder 0.2%, sugar 2%

354: Coconut milk 97.6 %, cocoa powder 0.4%, sugar 2%

514: Coconut milk 96 %, sugar 4%

439: Coconut milk 95.8 %, cocoa powder 0.2%, sugar 4%

452: Coconut milk 95.6 %, cocoa powder 0.4%, sugar 4%

All drinks samples are fortified with 0.15mg KI, 2.0mg $FeSO_4$, and 1.6 mg Retinol palmitate per 100g of sample

3.1.1 Appearance of fortified coconut milk based chocolate drinks

For appearance, scores by the panelist ranged from 7.87 to 8.70 on a scale of 9 for sample K2 (Coconut milk 99.8 % cocoa powder 0.2 %), and K9 (Coconut milk 95.6 %, cocoa powder 0.4%, sugar 4%) respectivelywith significant different at p>0.05. This means the score ranged from like very much to like extremely), this gave a positive impression about the appearance of the drink samples. Panelist appreciated the brown colouration imparted by cocoa powder to the drink.

3.1.2 Aroma of fortified coconut milk based chocolate drinks

In term of aroma, samples K9 (Coconut milk 95.6 %, cocoa powder 0.4%, sugar 4%) was preferred most and sample K1 (Coconut milk 100 %), was the least preferred. There was significant difference between the samples at $P<0.05$. The scores ranged from 7.40 to 8.37 (like moderately to like extremely) for K1 and K9 respectivelywith significance difference between the samples at $p>0.05$. This means the cocoa powder flavour in the drink samples was appreciated by the panelists.

3.1.3 Taste of fortified coconut milk based chocolate drinks

The taste of the drink samples, ranged from 7.37 to 8.37 (like moderately to like very much) for K1 (Coconut milk 100 %), and K9 (Coconut milk 95.6 %, cocoa powder 0.4%, sugar 4%) respectively Sample K9 was preferred most and sample K1 was the least preferred. There was significant difference between the samples at $P<0.05$. Cocoa powder positively influenced the taste of the drink samples.

3.1.4 Mouth feel of fortified coconut milk based chocolate drinks

Mouth feel ranged from 7.53 (K1) to 8.50 (K9) there was significance difference between the samples. The lowest score was in K1 (Coconut milk 100 %) and K3 (Coconut milk 99.6 %, cocoa powder 0.4%) while highest was recorded for K9 (Coconut milk 95.6 %, cocoa powder 0.4%, sugar 4%). This means panelists like sample K9 extremly and sample K1 and K3 was liked moderately.K1 (Coconut milk 100 %), K2 (Coconut milk 99.8 % cocoa powder 0.2 %), K3 (Coconut milk 99.6 %, cocoa powder 0.4%), K4 (Coconut milk 98 %, sugar 2%), K5 (Coconut milk 97.8 %, cocoa powder 0.2%, sugar 2%), K6 (Coconut milk 97.6 %, cocoa powder 0.4%, sugar 2%), K7 (Coconut milk 96 %, sugar 4%), K8 (Coconut milk 95.8 %, cocoa powder 0.2%, sugar 4%), K9 (Coconut milk 95.6 %, cocoa powder 0.4%, sugar 4%).

3.1.5 General acceptability of fortified coconut milk based chocolate drinks

For overall acceptability, sample K9 (Coconut milk 95.6 %, cocoa powder 0.4%, sugar 4%) was the most preferred with the score of 8.30/9 (like very much) and the score was not significantly different from 8.03/9 forK8 (Coconut milk 95.8 %, cocoa powder 0.2%, sugar 4%), (like very much). Sample K7 (Coconut milk 96 %, sugar 4%), came third with the score of 7.77 (like very much) and it was not significantly different from samples K9 and K8. The least preferred samples was sample K3 (Coconut milk 99.6 %, cocoa powder 0.4%), followed by K1 (Coconut milk 100 %), K2 (Coconut milk 99.8 % cocoa powder 0.2 %) with score of 6.40 /9, 6.53/9 (like slightly) and 6.60 (moderately). This was similar to like very much obtained by (Yakum et al., 2022) on the sensory properties of plant based yoghurt. This implies that drink from coconut milk based chocolate drink was generally accepted by the panelists.

3.2.0 Rheological properties of fortified coconut milk based chocolate drinks

The rheological properties of dink samples were studied using the power law and the Arrhenius equation. Results are presented on table 2 and table 3

3.2.1 Rheological properties of drink samples using the Power law model

The relationship between viscosity and share rates at different temperatures of the drink samples were investigated using Power law model and results presented in table 1

The rheological parameters using the power law gave consistency index (m) as follows

At 10 ℃, consistency index (m) ranged from 0.003 to 0.0032 Ns^n/m^2 while flow behavior index (n) were all n<1. Coefficient of regression (r^2) ranged from 0.902 to 0.983(approximately 1).

At 20 ℃ consistency index (m) ranged from 0.011 to 0.020 Ns^n/m^2 while flow behavior index (n) were all n<1. Coefficient of regression (r^2) ranged from 0.833 to 0.973(approximately 1).

At 30 ℃ consistency index (m) ranged from 0.009 to 0.019 Ns^n/m^2 while flow behavior index (n) were all n<1. Coefficient of regression (r^2) ranged from 0.825 to 0.996(approximately 1).

At 40 ℃ consistency index (m) ranged from 0.008 to 0.012 Ns^n/m^2 and flow behavior index (n) n<1 for all drink samples. Coefficient of regression (r^2) ranged from 0.887to 0.997(approximately 1).

Table 2: Rheological properties of fortified drink samples using Power law model

T ℃	Power law Parameter	K1	K2	K3	K4	K5	K6	K7	K8	K9
	Intercept	-5.69	-5.754	-5.803	-5.795	-5.814	-5.789	-5.830	-5.748	-6.19
	m(Ns^n/m^2)	0.003	0.0032	0.0031	0.0030	0.0029	0.0031	0.0029	0.0032	0.003

10	Slope	-0.072	-0.104	-0.103	-0.099	-0.083	-0.086	-0.038	-0.077	-0.067
	N	0.928	0.896	0.897	0.901	0.917	0.914	0.9612	0.923	0.932
	$\mathbf{r^2}$	0.930	0.949	0.9073	0.947	0.902	0.983	0.965	0.902	0.915
	Intercept	-4.501	-4.200	-4.003	-3.891	-4.185	-3.937	-4.214	-4.158	-3.933
	m(Ns^n/m^2)	0.011	0.014	0.018	0.012	0.015	0.019	0.015	0.016	0.020
20	Slope	-0.091	-0.166	-0.248	-0.246	-0.311	-0.264	-0.347	-0.332	-0.273
	N	0.908	0.834	0.752	0.753	0.688	0.736	0.653	0.668	0.727
	$\mathbf{r^2}$	0.833	0.964	0.965	0.965	0.955	0.932	0.923	0.919	0.973
	Intercept	-4.757	-4.271	-4.173	-4.055	-4.080	-4.195	-4.247	-4.173	-4.056
	m(Ns^n/m^2)	0.009	0.014	0.015	0.016	0.017	0.018	0.016	0.017	0.019
30	Slope	-0.123	-0.201	-0.190	-0.171	-0.175	-0.237	-0.253	-0.242	-0.249
	N	0.877	0.799	0.810	0.829	0.825	0.763	0.747	0.758	0.751
	$\mathbf{r^2}$	0.996	0.837	0.825	0.908	0.903	0.899	0.863	0.854	0.984
	Intercept	-5.329	-4.626	-4.647	-4.512	-4.932	-4.746	-4.747	-4.569	-4.401
	m(Ns^n/m^2)	0.008	0.009	0.010	0.010	0.010	0.011	0.010	0.011	0.012
40	Slope	-0.308	-0.109	-0.100	-0.108	-0.216	-0.189	-0.182	-0.122	-0.103
	N	0.918	0.891	0.900	0.892	0.839	0.811	0.818	0.878	0.897
	$\mathbf{r^2}$	0.934	0.948	0.889	0.960	0.887	0.973	0.914	0.997	0.974

Key

K1: Coconut milk 100 %
K2: Coconut milk 99.8 % cocoa powder 0.2 %
K3: Coconut milk 99.6 %, cocoa powder 0.4%
K4: Coconut milk 98 %, sugar 2%
K5: Coconut milk 97.8 %, cocoa powder 0.2%, sugar 2%
K6: Coconut milk 97.6 %, cocoa powder 0.4%, sugar 2%
K7: Coconut milk 96 %, sugar 4%
K8: Coconut milk 95.8 %, cocoa powder 0.2%, sugar 4%
K9: Coconut milk 95.6 %, cocoa powder 0.4%, sugar 4%
M = Consistency index (Ns^n/m^2)
n = Flow behavior index
$\mathbf{r^2}$ **=** Coefficient of regression

All drinks samples were fortified with 0.15mg KI, 2.0mg $FeSO_4$, and 1.6 mg Retinol palmitate per 100g of sample

3.2.1.1 Drinks behavior with Power law model

The changes in viscosity with shear rate for the fortified coconut milk based chocolate drink indicated that, viscosity decreased with shear rate and temperature in all the drink samples.

3.2.1.2 Consistency index (m) of drink samples

Apparent viscosity and consistency index of drink decreased with increasing temperatures.

Consistency index is an indication of the viscous nature of the drink (Alakali & Irtwange, 2015)

3.2.1.3 Flow behaviour index (n) of drink samples

It was observed that flow behaviour indices of drinks were all less than 1($n < 1$). Similar results for flow behavior index (n) ranging from 0.657 to 0.723 was obtained by Silva et al 2020 on Rheological behavior of plant-based beverages. The flow behavior index did not show major change with temperature and its value was generally below one, hence coconut milk based chocolate drink exhibit pseudoplastic behavior(Gupta et al., 2022).The increase in viscosity (shear stress) gives more than proportional increase in share rate. The curve is convex and begins at the origin. It is the most common type of non neutonian behavior. The viscosity is dependent on shear rate. And it obeys the power law equation(Silva et al., 2020).

3.2.1.4 Coefficient of regression (r^2) for drink samples

The high r^2 values indicates that the power law model is appropriate for describing the rheological characteristics of fortified coconut milk based chocolate drink

Apparent viscosity decreases with increasing shear rate, indicating shear thinning behavior (Ashaver et al., 2023).

3.3.0 Rheological properties of drink samples using the Arrhenius equation model

The relationship between temperature and viscosity at different share rates of the drink samples was investigation using Arrhenius equation and results are presented in table 2

At rpm 5, frequency factor (μo) for drink samples ranged from 3.3×10^{-6} to 4.1×10^{-7} , Activation energy (Ea) in terms of energy per mole (KJ/mol) from 24.84 to 30.70 KJ/mol, Coefficient of regression (r^2) from 0.810 to 0.952 (Approximately 1).

At rpm 10,frequency factor (μo) for drink samples ranged from 1.9×10^{-5} to 1.7×10^{-7} , Activation energy (Ea) in terms of energy per mole (KJ/mol) from 22.25 to 26.81 KJ/mol, Coefficient of regression (r^2) from 0.810 to 0.993 (Approximately 1).

At rpm 20, frequency factor (μo) for drink samples ranged from 5.1×10^{-6} to 9.7×10^{-6} , Activation energy (Ea) in terms of energy per mole (KJ/mol) from 18.93 to 22.96 KJ/mol, Coefficient of regression (r^2) from 0.838 to 0.948 (Approximately 1).

At rpm 50, frequency factor (μo) for drink samples ranged from 1.1 x 10^{-5} to 9.7 x 10^{-6} , Activation energy (Ea) in terms of energy per mole (KJ/mol) from 17.68 to 19.82 KJ/mol, Coefficient of regression (r^2) from 0.803 to 0.961 (Approximately 1).

At rpm 100,frequency factor (μo) for drink samples ranged from 3.1 x 10^{-5} to 9.9 x 10^{-6} , Activation energy (Ea) in terms of energy per mole (KJ/mol) from 15.55 to 19.45 KJ/mol, Coefficient of regression (r^2) from 0.817 to 0.997 (Approximately 1).

Table 3 Rheological of fortified drink samples using Arrhenius equation model

Share rate	**Arrhenius**	**Sample**								
Rpm	Parameter	K1	K2	K3	K4	K5	K6	K7	K8	K9
	Intercept	-13.32	-14.39	-14.66	-15.46	-14.04	-14.93	-15.09	-15.66	-16.80
	μ_o	1.6E-6	5.6E-7	4.3E-7	1.9E-7	7.9E-7	3.3E-7	2.7E-7	1.6E-7	5.1E-8
5	**Slope**	2987.7	3237.9	3387.1	3317.3	3473.7	3517.0	3589.2	3627.6	3692.6
	Ea(KJ/mol)	24.84	26.92	28.16	27.58	28.88	29.24	29.84	30.16	30.70
	r^2	0.938	0.952	0.929	0.915	0.845	0.859	0.939	0.876	0.929
	Intercept	-10.85	-12.59	-14.11	-12.17	-13.23	-14.30	-12.97	-14.49	-15.59
	μ_o	1.9E-5	3.4E-06	1.0E-07	7.4E-7	1.8E-6	6.2E-7	2.2E-6	5.1E-7	1.7E-7
10	**Slope**	2676.2	2969.7	3115.2	2927.6	3013.0	3133.3	3128.5	3193.4	3224.7
	Ea(KJ/mol)	22.25	24.69	25.90	24.34	25.05	26.05	26.01	26.55	26.81
	r^2	0.983	0.993	0.953	0.947	0.837	0.912	0.810	0.972	0.915
	Intercept	-12.18	-14.7.0	-12.460	-11.30	-13.05	-13.14	-10.274	-11.55	-12.17
	μ_o	5.1E-6	4.1E-6	3.9E-6	1.2E-6	2.2E-6	2.0E-6	3.5E-6	9.7E-6	5.2E-6
20	**Slope**	2276.9	2487.4	2504.2	2666.6	2694.3	2724.3	2681.0	2720.7	2761.6
	Ea(KJ/mol)	18.93	20.68	20.82	22.17	22.40	22.65	22.29	22.62	22.96
	r^2	0.858	0.941	0.867	0.892	0.838	0.862	0.944	0.933	0.948
	Intercept	-13.80	-13.44	-11.41	-9.43	-12.23	-12.791	-11.55	-11.96	-11.95
	μ_o	1.0E-6	1.4E-6	1.1E-5	8.0E-5	4.9E-6	2.8E-06	9.7E-6	6.3E-6	6.E-6
50	**Slope**	2126.5	2297.3	2355.1	2201.1	2351.5	2373.1	2284.1	2341.8	2383.9
	Ea(KJ/mol)	17.68	19.10	19.58	18.30	19.55	19.73	18.99	19.47	19.82
	r^2	0.816	0.923	0.831	0.820	0.934	0.904	0.803	0.901	0.961
	Intercept	-13.54	-12.58	-10.87	-10.38	-12.97	-12.87	-11.52	-11.85	-11.93
	μ_o	1.3E-6	3.4E-06	1.9E-05	3.1E-5	2.3E-6	2.6E-6	9.9E-6	7.1E-6	6.6E-6
100	**Slope**	1870.3	1896.8	1975.0	1910.0	1967.8	2079.6	2127.7	2270.9	2339.4
	Ea(KJ/mol)	15.55	15.77	16.42	15.88	16.36	17.29	17.69	18.88	19.45
	r^2	0.867	0.917	0.890	0.817	0.875	0.828	0.894	0.889	0.997

KEY

K1: Coconut milk 100 %
K2: Coconut milk 99.8 % cocoa powder 0.2 %
K3: Coconut milk 99.6 %, cocoa powder 0.4%
K4: Coconut milk 98 %, sugar 2%
K5: Coconut milk 97.8 %, cocoa powder 0.2%, sugar 2%
K6: Coconut milk 97.6 %, cocoa powder 0.4%, sugar 2%
K7: Coconut milk 96 %, sugar 4%
K8: Coconut milk 95.8 %, cocoa powder 0.2%, sugar 4%
K9: Coconut milk 95.6 %, cocoa powder 0.4%, sugar 4%
μ_o = frequency factor (Arrhenius constant)

Ea= Activation energy in terms of energy per mole (KJ/mol)
r^2 = Coefficient of regression

All drinks samples are fortified with 0.15 mg KI, 2.0 mg $FeSO_4$, and 1.6 mg Retinol palmitate per 100g of sample

3.3.1Drinks behavior with Arrhenius equation

There was an inverse relationship between viscosity and temperature hence viscosity decreases as temperature increases and thus exhibits Arrhenius type relationship. Arrhenius equation describes the relationship between the rate of reaction and temperatures for many physical and chemical reactions(Correa et al., 2018).

3.3.2 Frequency factor (μo) of fortified drink samples

There was an inverse relationship between viscosity and temperature hence viscosity decreases as temperature increases and thus exhibits Arrhenius type relationship

3.3.3. Activation energy (Ea) of drink samples

Activation energy (Ea) is defined as minimum energy required which overcomes the energy barrier before the elementary flow can occur(Azeddine et al., 2023).

The viscous flow occurs as a sequence of events which are shift of particles in the direction of shear force action from one equilibrium position to another position by overcoming a potential energy barrier. The barrier height determines the free activation energy of viscous flow. Higher activation energy values indicate a greater influence of temperature on the viscosity, i.e. more rapid change in viscosity with temperature. When temperature increased, the thermal energy of the molecules and intermolecular spacing increased significantly, which lead to decrease in the magnitude of viscosity

3.3.4 Coefficient of regression (r^2) of drink samples using the Arrhenius equation

The high r^2 values indicates that the Arrhenius equation is appropriate for describing the rheological characteristics of fortified coconut milk based chocolate drink since the values were all approximately 1.

Arrhenius equation describes the relationship between the rate of reaction and temperatures for many physical and chemical reactions(Correa et al., 2018)

4.0 CONCLUSION

The production of fortified coconut milk based chocolate drinks is possible and looking at its sensory profile it was generally accepted by the panelist

The flow behaviour indices (n) of drinks did not show major change with temperature and its value were all less than 1(n < 1). This implies coconut milk based chocolate drink exhibit pseudoplastic behaviorthus a non-Newtonian fluid.There is an inverse relationship between viscosity and temperature hence viscosity decreases as temperature increases and thus exhibits Arrhenius type relationship.Cocoa powder and sugar levels improved the sensory properties of the drink samples since the overall best sample contains 0.4 % cocoa powder and 4 % sugar content.

Comment [AB19]: The sentence has a couple of grammatical errors and can be improved for clarity. Here's a corrected version:

The production of fortified coconut milk-based chocolate drinks appears feasible. Sensory evaluation indicated that the panelists generally accepted the drinks.

Comment [AB20]: The paragraph is mostly grammatically correct, but there can be some improvements for clarity and flow. Here's a revised version:

The flow behavior index (n) of the drinks exhibited minimal change with temperature. All values were less than 1 (n < 1), indicating pseudoplastic behavior, a characteristic of non-Newtonian fluids. This aligns with the known inverse relationship between viscosity and temperature. As temperature increases, viscosity decreases, demonstrating an Arrhenius-type relationship.

Comment [AB21]: improved" rephrased to "improved with higher...levels" for better clarity on the impact of cocoa and sugar content.

Comment [AB22]: "since" replaced with "This is evident from" to establish a clearer cause-and-effect relationship between the levels and sensory properties.

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