Colour and Rheological Properties of Some Cocoa and Chocolate Products During Storage

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ABSTRACT

Cocoa and cocoa-based products differ in composition and structure, and these differences can affect their colour and flow behaviour during storage. This study evaluated the colour and rheological properties of selected cocoa-based products stored for six weeks at 25 °C. The products were natural cocoa liquor, natural cocoa butter, natural cocoa powder, milk chocolate, dark chocolate, extra dark chocolate, peanut chocolate spread, and chocolate drink. Colour parameters, total colour difference, viscosity, amplitude sweep, and frequency sweep were determined. Most of the products remained within the dark colour region during storage, while natural cocoa butter showed the highest lightness values. Significant changes were observed in the colour parameters during storage, showing that the products did not have the same level of colour stability. The available viscosity results for natural cocoa liquor, natural cocoa butter, natural cocoa powder, peanut chocolate spread, and chocolate drink showed shear-thinning behaviour, with viscosity decreasing as shear rate increased. The amplitude and frequency sweep results also showed differences in storage modulus, loss modulus, linear viscoelastic region, and yield behaviour among the products. These findings show that cocoa-based products respond differently during storage depending on their product type and structure. The study provides useful information for storage control, product handling, and quality management in cocoa and chocolate processing.

Keywords: Cocoa-based products, chocolate, colour, rheological properties, storage modulus, loss modulus, viscosity, Storage stability

INTRODUCTION

Cocoa (*Theobroma cacao* L.) is an important raw material for the production of cocoa liquor, cocoa butter, cocoa powder, chocolate, spreads, and cocoa-based beverages. Its quality is influenced by genotype, growing environment, fermentation, drying, roasting, refining, conching, tempering, formulation, and storage. Although the traditional classification of cocoa into Criollo, Forastero, and Trinitario is still commonly used in industry, molecular studies show that cacao diversity is broader than this system. Motamayor et al. (2008) identified ten genetic clusters within *Theobroma cacao*, namely Marañon, Curaray, Criollo, Iquitos, Nanay, Contamana, Amelonado, Purús, Nacional and Guiana. This wider classification is important because cocoa beans from different genetic and geographical backgrounds may differ in fat composition, polyphenol content, flavour precursors and processing behaviour. These differences may influence the colour, rheological, and physicochemical properties of cocoa-derived products.

Chocolate and cocoa-based products are made up of cocoa solids, cocoa butter, sugar, milk solids, emulsifiers, and other ingredients. These ingredients form a complex system where solid particles are dispersed in a fat phase. In chocolate, cocoa butter forms the main fat phase, while cocoa solids, sugar, and milk solids form the dispersed solid phase (Bahari and Akoh, 2018). The interaction between these ingredients affects colour, texture, flow behaviour, mouthfeel, and storage stability. These properties are

influenced by particle size distribution, fat content, emulsifier concentration, moisture, and processing conditions (Afoakwa, Paterson and Fowler, 2007; Afoakwa, Paterson and Fowler, 2008). In recent chocolate production, ingredients such as nuts, plant-based materials, berries, and tropical fruits have also been incorporated to improve flavour, nutritional value, and consumer acceptability. However, such ingredients may change the fat phase, solid particle content, and moisture level of the product, thereby affecting viscosity, yield stress, colour, storage stability, and sensory quality (Medina-Mendoza et al., 2021).

Rheological properties are important quality indicators in cocoa and chocolate processing because they affect pumping, mixing, coating, moulding, filling, mouthfeel, and consumer acceptance. This is because chocolate behaves as a concentrated suspension, where the interaction between the fat phase and dispersed particles influences its flow behaviour (Bahari and Akoh, 2018). Its flow behaviour is strongly affected by particle size distribution, fat content, emulsifier concentration, moisture level, temperature, and processing conditions (Afoakwa, Paterson and Fowler, 2007). Afoakwa, Paterson and Fowler (2008) also showed that particle size distribution, fat content, and lecithin content significantly affect Casson plastic viscosity, Casson yield value, apparent viscosity, and thixotropy in dark chocolate.

The measurement of chocolate viscosity is method-sensitive because the results depend on temperature, shear conditions, sample preparation, and the model used for interpretation. The Casson model has been widely used to describe chocolate flow behaviour, especially in relation to yield stress and plastic viscosity. Servais, Ranc and Roberts (2003) described a reference method for determining the viscosity of chocolate and related cocoa products using factory-grade viscometers, while Eischen and Windhab (2002) discussed viscosity measurement procedures for cocoa and chocolate products. These methods are useful in this study because they provide a basis for evaluating changes in the flow behaviour of cocoa-based products during storage.

Colour is also an important quality attribute in cocoa and chocolate products because it affects consumer perception and may indicate changes in composition or stability. Changes in lightness, redness, yellowness, and total colour difference may result from pigment changes, oxidation, moisture movement, surface drying, sugar bloom, fat bloom, and fat crystal rearrangement. Fat bloom is particularly important in chocolate products because it can produce a whitish or grey surface appearance and reduce product acceptability. Lonchampt and Hartel (2004) explained that fat bloom is associated with fat migration, cocoa butter crystallisation, and storage conditions. Nightingale, Lee and Engeseth (2011) also reported that storage can affect the texture and polymorphic stability of dark chocolate. Pastor et al. (2007) further showed that storage temperature affects the gloss and colour of dark chocolate.

Recent studies have also shown that cocoa butter structure is important in explaining the quality of chocolate and cocoa-based products. Cocoa butter contains major fatty acids such as palmitic, stearic and oleic acids, which occur mainly in triglycerides such as 1,3-dipalmitoyl-2-oleoyl-sn-glycerol (POP), 1-palmitoyl-2-oleoyl-3-stearoyl-sn-glycerol (POS) and 1,3-distearoyl-2-oleoyl-sn-glycerol (SOS). These triglycerides influence crystallisation, polymorphic transition, melting behaviour, hardness, gloss and rheological behaviour in chocolate products. During storage, changes in cocoa butter crystal form may affect texture, surface appearance and resistance to fat bloom (Suri and Basu, 2022; Balcázar-Zumaeta et al., 2026). This is important for the present study because the selected products differed in fat content, cocoa solid content and physical form, and these differences may explain why their colour and rheological behaviour changed differently during storage.

Several studies have examined the rheology, texture, and storage stability of chocolate and cocoa-based products. These studies have shown that particle size distribution, fat content, emulsifier concentration, temperature, and storage conditions can affect viscosity, yield stress, texture, fat crystallisation, and product stability (Afoakwa, Paterson and Fowler, 2007; Afoakwa, Paterson and Fowler, 2008; Servais, Ranc and Roberts, 2003; Lonchampt and Hartel, 2004; Nightingale, Lee and Engeseth, 2011; Szydłowska-Czerniak et al., 2017; Dias et al., 2022; Yucel et al., 2022; Hendrik et al., 2023; Chi et al., 2025; Balcázar-Zumaeta et al., 2026; Chandra et al., 2026). However, most studies focus on chocolate or cocoa butter alone, while less attention has been given to comparing different cocoa-derived product matrices from the same industrial

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setting. This is important because cocoa liquor, cocoa butter, cocoa powder, chocolate bars, chocolate spread and chocolate drink differ in fat content, particle structure, added ingredients and moisture sensitivity (Balcázar-Zumaeta et al., 2026). Studying these products together can provide practical information on which product types are more susceptible to colour and rheological changes during storage. Therefore, this study determined the colour and rheological properties of selected cocoa and chocolate products during a six-week storage period, with emphasis on product stability and quality control under ambient storage conditions.

MATERIALS AND METHODS

Source of Materials

The study was conducted using eight cocoa-based products obtained from Niche Cocoa Industry Limited, Tema, Ghana. The sampling and manufacturing site was georeferenced at 5°41′29.3″N, 0°01′16.4″E. The products were natural cocoa liquor (A1), natural cocoa butter (B1), natural cocoa powder (C1), Niche milk chocolate (D1), Niche dark chocolate (E1), Niche extra dark chocolate (F1), Niche peanut chocolate spread (G1), and Niche chocolate drink (H1). The batch number, production date, expiry date, and storage period before analysis were recorded for each product, as shown in Table 1.

Sample Preparation Before Storage

Each product sample was packaged in appropriate food-grade materials consistent with the company's post-production practices. The samples were divided into six containers to represent the six weeks of storage. One container was taken each week for analysis to reduce repeated opening and handling of the same sample. The samples were stored at 25 °C in a temperature-controlled oven and were protected from direct light and contamination during storage. The storage period before analysis shown in Table 1 represents the age of each finished product at the start of the study, while the six-week storage period refers to the controlled experimental storage period after sample collection.

Table 1: Samples and their details

Product Name	Sample code	Batch Number	Production Date	Expiry Date	Storage Period Before Analysis
Natural Cocoa Liquor	A1	T8D244372	27-Oct-2024	26-Oct-2026	1 week
Natural Cocoa Butter	B1	1244357	25-Oct-2024	24-Oct-2026	1 week
Natural Cocoa Powder	C1	3242731	03-Jul-2024	02-Jul-2027	12 weeks
Milk Chocolates	D1	4242911	15-Jul-2024	15-Jul-2025	12 weeks
Dark Chocolates	E1	5234821 5231441	03-Jul-2024 04-Apr-2024	08-May-2024 04-Sep-2024	68 weeks 24 weeks
Extra Dark Chocolates	F1	12232231	24-May-2022	13-Dec-2024	116 weeks

Chocolate Spread (Peanut)	G1	SP242141	25-May-2024	25-May-2025	20 weeks
Chocolate Drink	H1	CDS24233	05-Jun-2024	05-Mar-2025	12 weeks

Preparation of Samples for Analysis

Before analysis using the Casson model, liquid and semi-solid samples, including cocoa liquor and peanut chocolate spread, were gently mixed to obtain uniform samples and reduce trapped air. Cocoa powder and chocolate drink were mixed thoroughly before sampling. Solid chocolate samples were prepared into smaller portions before analysis to improve uniformity. Before rheological measurement, the samples were equilibrated and pre-melted at 35 °C before being placed on the rheometer plate. The same preparation procedure was followed for all storage weeks to reduce variation caused by sample handling.

Rheological Analysis

Rheological measurements were carried out using an Anton Paar rheometer, model MCR 92, serial number 84277947, with RheoCompass software (Anton Paar GmbH, Graz, Austria). A 50 mm parallel plate geometry (PP50) was used with a measurement gap of 1 mm. The measurement temperature was held constant at 25 °C using the rheometer temperature-control system (Kpodo et al. 2026). The flow behaviour was assessed using the programmed flow-curve method in RheoCompass software. Apparent viscosity was measured for selected samples as a function of shear rate over approximately 0.1–100 s^{-1} using 21 documented shear-rate points. The Casson model was used to estimate yield stress and plastic viscosity because it has been widely applied to chocolate and cocoa-based suspensions (Afoakwa, Paterson and Fowler, 2008). The measurement protocol was also guided by methods used for chocolate and related cocoa products (Servais, Ranc and Roberts, 2003; Eischen and Windhab, 2002).

Oscillatory amplitude sweep measurements were carried out at an angular frequency of 1-100 rad/s. The samples were analysed over a shear strain range of 0.0001–1000% and a shear stress range of 0.01–100 Pa. The amplitude sweep was used to determine the linear viscoelastic region and to measure the storage modulus (G′) and loss modulus (G″). Frequency sweep measurements were conducted within the linear viscoelastic region over an angular frequency range of 0.1 to 100 rad/s.

Colour Determination

Colour was measured using a Konica Minolta Chroma Meter, model CR-410 (Konica Minolta, Inc., Tokyo, Japan), following the CIE L*a*b* colour system. The instrument was calibrated with a blank white tile before measurement. The L* value represented lightness, ranging from 0 for dark colour to 100 for bright colour. The a* value represented the green-red coordinate, where negative values indicate greenness and positive values indicate redness. The b* value represented the blue-yellow coordinate, where negative values indicate blueness and positive values indicate yellowness. For colour measurement, chocolate spread, cocoa powder solution at 15% concentration, and chocolate drink were transferred into Petri dishes to cover the base before readings were taken. Chocolate bar samples were measured directly by placing the chromameter on the surface of the bar. Measurements were taken at three different points on each sample surface, and the mean value was used for analysis.

The total colour difference was calculated as:

$$\Delta E^* = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2}$$

where L_1*, a_1*, and b_1* represent the initial colour values, and L_2*, a_2*, and b_2* represent the colour values

after storage.

The Week 1 colour values were used as the reference values for calculating ΔE* during storage.

Statistical Analysis

All experiments were conducted in triplicate, and results were expressed as mean ± standard deviation. Data analysis was performed using IBM SPSS Statistics (Version 27.0). One-way ANOVA was applied to determine statistically significant differences ($p < 0.05$) among samples over the six-week storage period. Post hoc comparisons were conducted using Tukey's HSD test to identify differences between storage intervals.

RESULTS AND DISCUSSION

This section presents and discusses the colour and rheological properties of the eight cocoa-based products during six weeks of storage. The products were natural cocoa liquor (A1), natural cocoa butter (B1), natural cocoa powder (C1), Niche milk chocolate (D1), Niche dark chocolate (E1), Niche extra dark chocolate (F1), Niche peanut chocolate spread (G1), and Niche chocolate drink (H1).

Colour Properties of Cocoa and Chocolate Samples

Colour is an important quality attribute in cocoa and chocolate products because it affects appearance and consumer perception. The measured colour parameters were L*, a*, b*, and ΔE* (Tables 2–9). The L* value indicates lightness, with lower values showing darker colour and higher values showing brighter colour. The a* value indicates the green-red coordinate, where negative values show greenness and positive values show redness. The b* value indicates the blue-yellow coordinate, where negative values show blueness and positive values show yellowness. The ΔE was calculated against a blank empty petri dish.

The results showed that A1, C1, D1, E1, F1, G1, and H1 remained within the dark colour region, with L* values below 50 throughout storage. This agrees with the presence of cocoa solids and brown colour compounds in these products. In contrast, B1 showed higher L* values, ranging from 82.41 to 92.93, indicating a brighter product. This is expected because cocoa butter is mainly a fat phase and contains fewer non-fat cocoa solids than cocoa liquor, cocoa powder, and chocolate products.

The a* values also differed among the products. B1 had negative a* values, ranging from –4.42 to –5.32, showing a slight green tendency. The remaining samples had positive a* values, showing a red tendency. The b* values were positive in all samples, indicating a yellow tendency. The higher b* values recorded for B1 agree with the pale-yellow colour of natural cocoa butter.

Changes in L*, a*, and b* values across the storage period indicate that storage affected the measured colour coordinates of the products. These changes were not the same for all samples, showing that the products responded differently during storage. The differences may be linked to product composition, cocoa solid content, fat content, particle distribution, and physical form. In chocolate products, colour changes may also be associated with surface changes such as fat bloom, which can produce a whitish or grey surface appearance. Fat bloom is associated with fat migration, cocoa butter crystallisation, and storage conditions (Lonchampt and Hartel, 2004). Storage-related changes in texture, polymorphic stability, gloss, and colour of chocolate have also been reported by Nightingale, Lee and Engeseth (2011) and Pastor et al. (2007).

The present colour results agree with previous studies showing that storage can affect chocolate appearance through changes in surface structure and cocoa butter crystallisation. Balcázar-Zumaeta et al. (2026) explained that cocoa butter can occur in different polymorphic forms, and that changes in these forms may influence gloss, hardness, surface appearance and fat bloom development. In the present study, cocoa butter had the highest L* values because it was mainly a fat phase, while cocoa liquor, cocoa powder and chocolate products remained darker because of their higher cocoa solid content. This comparison shows that the colour behaviour of the samples was linked to product composition and not only to storage time.

Table 2. Average L*, a*, b* and ΔE* readings of sample A1 (Natural Cocoa Liquor).

Weeks	Sample code	L*	a*	b*	ΔE*
Week 1	A1	37.44 ± 0.16^{b}	8.97 ± 0.05^{c}	15.10 ± 0.09^{b}	60.56 ± 0.14^{c}
Week 2	A1	37.73 ± 0.21^{b}	8.53 ± 0.10^{bc}	14.78 ± 0.21^{b}	59.84 ± 0.37^{b}
Week 3	A1	36.35 ± 0.50^{a}	7.09 ± 1.19^{a}	10.23 ± 3.55^{a}	60.73 ± 0.41^{c}
Week 4	A1	37.41 ± 0.06^{b}	8.88 ± 0.07^{bc}	14.75 ± 0.08^{b}	60.50 ± 0.07^{c}
Week 5	A1	36.49 ± 0.01^{a}	7.60 ± 0.02^{ab}	12.39 ± 0.01^{a}	60.85 ± 0.01^{c}
Week 6	A1	38.57 ± 0.08^{c}	$7.60 \pm 0.03^{a,b}$	14.77 ± 0.01^{b}	15.64 ± 0.02^{a}

Samples were analysed at a 95% confidence level. Different letters represent differences in the same column.

Table 3. Average L*, a*, b* and ΔE* readings of sample B1 (Natural Cocoa Butter).

Weeks	Sample code	L*	a*	b*	ΔE*
Week 1	B1	84.64 ± 0.13^{c}	-5.27 ± 0.02^{a}	34.03 ± 0.20^{e}	32.62 ± 0.14^{d}
Week 2	B1	83.62 ± 0.65^{b}	-4.71 ± 0.07^{b}	31.43 ± 0.47^{d}	30.57 ± 0.18^{c}
Week 3	B1	82.41 ± 0.38^{a}	-4.42 ± 0.05^{d}	25.09 ± 0.12^{a}	24.54 ± 0.54^{a}
Week 4	B1	86.25 ± 0.04^{d}	-4.54 ± 0.03^{c}	39.87 ± 0.07^{c}	27.87 ± 0.21^{b}
Week 5	B1	86.37 ± 0.18^{d}	-4.54 ± 0.02^{c}	29.24 ± 0.06^{b}	27.47 ± 0.03^{b}
Week 6	B1	92.93 ± 0.02^{e}	-5.32 ± 0.02^{a}	36.37 ± 0.01^{f}	68.48 ± 0.02^{e}

Samples were analysed at a 95% confidence level. Different letters represent differences in the same column.

Table 4. Average L*, a*, b* and ΔE* readings of sample C1 (Natural Cocoa Powder).

Weeks	Sample code	L*	a*	b*	ΔE*
Week 1	C1	38.87 ± 0.14^{c}	8.60 ± 0.02^{b}	13.14 ± 0.03^{b}	58.77 ± 0.14^{b}
Week 2	C1	32.06 ± 0.06^{a}	6.20 ± 0.02^{a}	8.01 ± 0.05^{a}	63.55 ± 0.06^{c}
Week 3	C1	38.63 ± 0.20^{bc}	9.26 ± 0.07^{d}	14.42 ± 0.11^{c}	57.31 ± 3.61^{b}
Week 4	C1	38.51 ± 0.13^{b}	8.79 ± 0.12^{c}	13.27 ± 0.04^{b}	59.17 ± 0.15^{b}
Week 5	C1	38.33 ± 0.09^{b}	9.10 ± 0.09^{d}	14.39 ± 0.12^{c}	59.59 ± 0.05^{bc}
Week 6	C1	41.63 ± 0.09^{d}	9.59 ± 0.01^{e}	17.86 ± 0.02^{d}	20.11 ± 0.04^{a}

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Samples were analyzed at a 95% confidence level. Different letters represent differences in the same column.

Table 5. Average L*, a*, b* and ΔE* readings of sample D1 (Niche Milk Chocolate).

Weeks	Sample code	L*	a*	b*	ΔE*
Week 1	D1	35.23 ± 0.02 [a]	8.12 ± 0.03 [a]	9.46 ± 0.03 [a]	61.82± 0.01 [e]
Week 2	D1	36.81±0.18 [bc]	9.66±0.08 [d]	12.31±0.21 [c]	60.82±0.20 [cd]
Week 3	D1	37.03±0.04 [c]	9.81±0.03 [e]	13.11±0.03 [d]	60.75±0.04 [c]
Week 4	D1	36.73±0.14 [b]	9.87±0.02 [e]	13.18±0.08 [d]	61.07±0.16 [d]
Week 5	D1	38.40±0.01 [d]	9.30±0.02 [b]	12.00±0.03 [b]	59.17±0.01 [b]
Week 6	D1	42.24±0.10 [e]	9.52±0.03 [c]	15.85±0.07 [e]	18.78±0.07 [d]

Samples were analyzed at a 95% confidence level. Different letters represent differences in the same column.

Table 6. Average L*, a*, b* and ΔE* readings of sample E1 (Niche Dark Chocolate).

Weeks	Sample code	L*	a*	b*	ΔE*
Week 1	E1	29.77±0.06 [a]	5.77±0.01 [a]	4.82 ±0.01 [a]	66.72±0.07[e]
Week 2	E1	33.07±0.07 [b]	7.92±0.08 [c]	7.36±0.12 [bc]	63.77±0.08 [c]
Week 3	E1	34.04±0.43 [c]	7.90±0.08 [bc]	7.52±0.09 [c]	62.89±0.39 [b]
Week 4	E1	34.35±0.04 [c]	7.78±0.01 [bc]	7.16±0.02 [b]	62.48±0.04 [b]
Week 5	E1	32.61±0.03 [b]	8.13±0.04 [d]	8.05±0.04 [d]	64.30±0.03 [d]
Week 6	E1	37.07±0.12 [d]	7.76±0.07 [b]	10.56±0.09 [e]	12.00±0.09 [a]

Samples were analyzed at a 95% confidence level. Different letters represent differences in the same column.

Table 7. Average L*, a*, b* and ΔE* readings of sample F1 (Niche Extra Dark Chocolate).

Weeks	Sample code	L*	a*	b*	ΔE*
Week 1	F1	30.37±0.19 [b]	5.86±0.06 [a]	4.63±0.05 [a]	66.18±0.14 [e]
Week 2	F1	28.91±0.01 [a]	6.17±0.01 [b]	5.10±0.02 [b]	66.74±0.01 [f]
Week 3	F1	33.22±0.32 [c]	8.34±0.02 [d]	7.52±0.08 [d]	63.19±0.59 [d]
Week 4	F1	34.03±0.02 [d]	7.79±0.03 [c]	7.04±0.02 [c]	62.78±0.03 [c]

Week 5	F1	33.06±0.15 [c]	5.87±0.04 [a]	8.14±0.09 [e]	8.62±0.02 [a]
Week 6	F1	34.83±0.02 [e]	8.57±0.01 [e]	10.75±0.00 [f]	12.33±0.01 [b]

Samples were analyzed at a 95% confidence level. Different letters represent differences in the same column.

Table 8: Average L*, a*, b* and ΔE* readings of sample G1 (Niche Peanut Chocolate Spread).

Weeks	Sample code	L*	a*	b*	ΔE*
Week 1	G1	40.25±0.05 [c]	9.60±0.14 [a]	13.88±0.29 [ab]	57.71 ±0.12 [b]
Week 2	G1	39.33±0.18 [a]	9.60±0.09 [a]	13.54±0.13 [a]	58.54±0.16 [cd]
Week 3	G1	39.30±0.12 [a]	9.84±0.04 [c]	14.11±0.10 [bc]	59.05±0.58 [d]
Week 4	G1	40.16±0.03 [c]	9.82±0.01 [bc]	14.38±0.02 [c]	57.93±0.04 [bc]
Week 5	G1	39.70± 0.10 [b]	9.63±0.04 [ab]	13.72±0.12 [ab]	58.21±0.12 [bc]
Week 6	G1	44.37±0.14 [d]	9.88±0.06 [c]	17.55±0.14 [d]	21.19±0.06 [a]

Samples were analyzed at a 95% confidence level. Different letters represent differences in the same column.

Table 9: Average L*, a*, b* and ΔE* readings of sample H1 (Niche Chocolate Drink).

Weeks	Sample code	L*	a*	b*	ΔE*
Week 1	H1	45.94±0.17 [a]	7.24±0.26 [c]	12.02±0.22 [bc]	51.58±0.10 [b]
Week 2	H1	46.09±0.01 [a]	7.72±0.43 [c]	12.17±0.50 [c]	51.43±0.15 [b]
Week 3	H1	45.12±0.43 [a]	6.24±0.05 [ab]	11.00±0.08 [a]	51.93±0.53 [b]
Week 4	H1	45.43±0.72 [a]	6.10±0.03 [ab]	10.96±0.07 [a]	51.67±0.70 [b]
Week 5	H1	45.49±0.36 [a]	6.49±0.17 [b]	11.20±0.02 [ab]	51.50±0.35 [b]
Week 6	H1	49.10±0.64 [b]	5.77±0.17 [a]	15.35±0.51 [d]	21.23±0.53 [a]

Samples were analyzed at a 95% confidence level. Different letters represent differences in the same column.

Amplitude Sweep Behaviour

The amplitude sweep test was used to evaluate the viscoelastic behaviour of the samples under increasing strain. It helps to identify the linear viscoelastic region, where the structure of the sample remains stable under small deformation. In this region, the storage modulus (G′) represents the elastic component, while the loss modulus (G″) represents the viscous component. A reduction in G′ or G″ at higher strain indicates weakening of the internal structure and transition towards flow.

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The amplitude sweep results showed that the samples had different resistance to deformation during storage. The chocolate samples and the peanut chocolate spread showed measurable G′ and G″ values at low strain, indicating structured systems with some resistance to deformation. As strain increased, most curves showed a reduction in modulus values, suggesting structural breakdown. Representative amplitude sweep curves for the chocolate samples, peanut chocolate spread, and chocolate drink are shown in Fig. 1–5.

The chocolate samples generally showed higher modulus values than the chocolate drink, indicating stronger internal structures. This may be due to the presence of cocoa solids, sugar particles, milk solids, emulsifiers, and fat crystal networks in the chocolate matrix. The peanut chocolate spread also showed clear viscoelastic behaviour, but the curves varied across storage weeks. This may be related to changes in the interaction between fat, cocoa solids, peanut particles, sugar, and other ingredients during storage. Afoakwa, Paterson and Fowler (2008) reported that particle size distribution, fat content, and lecithin content affect the rheological properties of dark chocolate. Beckett (2009) also explained that fat composition, particle distribution, and processing conditions influence the structure and flow behaviour of chocolate products.

The chocolate drink showed lower modulus values compared with the chocolate samples and the spread, indicating a weaker structure and lower resistance to deformation. This may be related to its product form and weaker fat-based structural network compared with the chocolate samples. These findings are similar to reports that cocoa butter crystals and dispersed solid particles contribute to the internal structure of chocolate. It has been shown that cocoa butter crystallisation and polymorphic form influence hardness, texture, rheology and spreadability in fat-based products (Balcázar-Zumaeta et al., 2026). In the present study, the chocolate samples showed stronger viscoelastic behaviour than the chocolate drink. This could be attributed to the fact that the chocolate samples contained a more developed fat-based structure with cocoa solids, sugar particles and milk solids dispersed in the fat phase. The lower modulus values of the chocolate drink suggest a weaker structure and lower resistance to deformation. Taken together, the amplitude sweep results showed that the samples had different viscoelastic responses during storage, which may be related to variations in fat content, cocoa solid content, particle distribution, and product form.

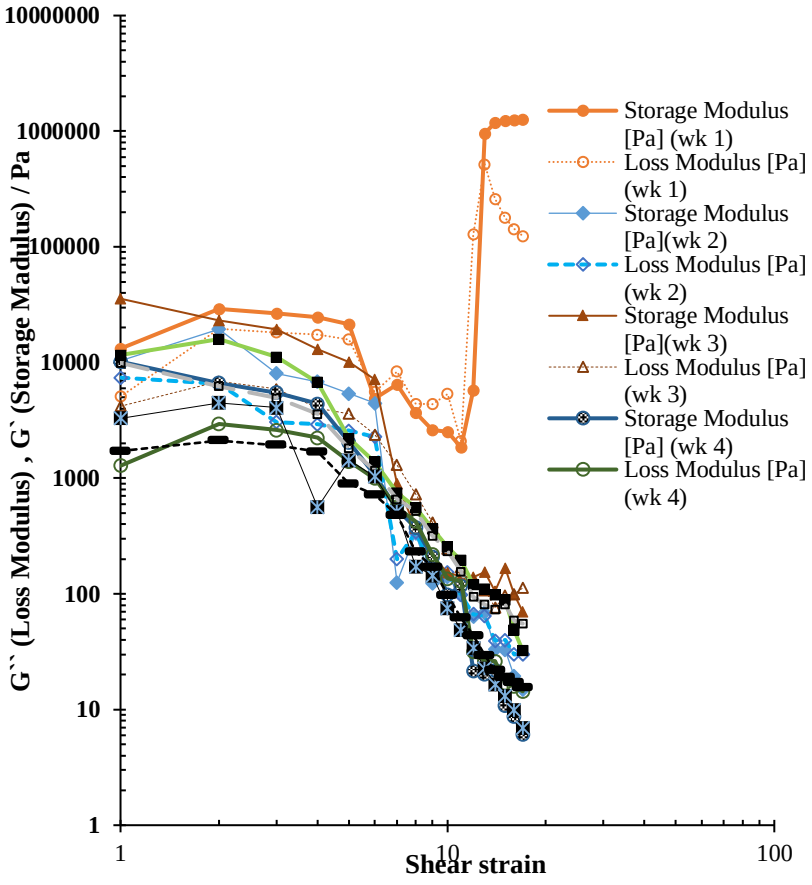


Fig. 1 Amplitude sweep for D1 (Niche Milk Chocolate) during a six-week storage period

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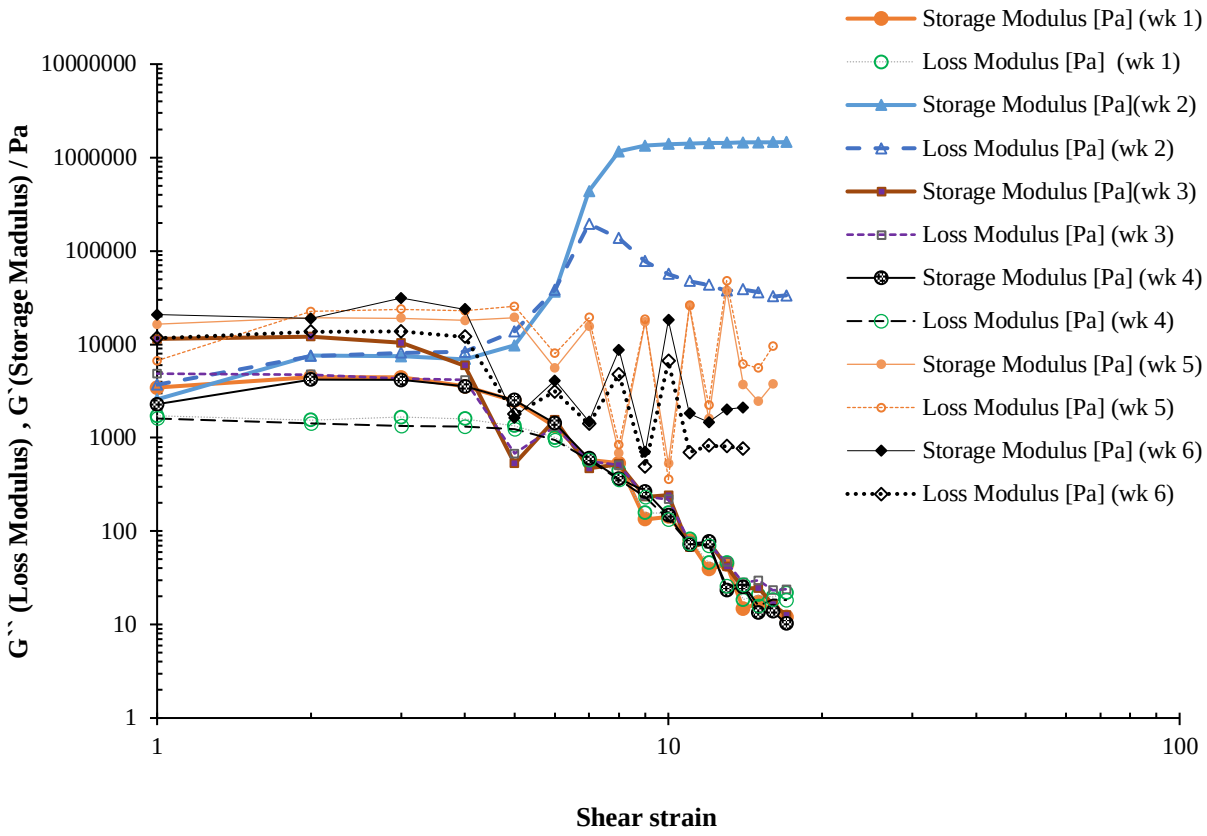


Fig. 2 Amplitude sweep for E1 (Niche Dark Chocolate) during a six-week storage period

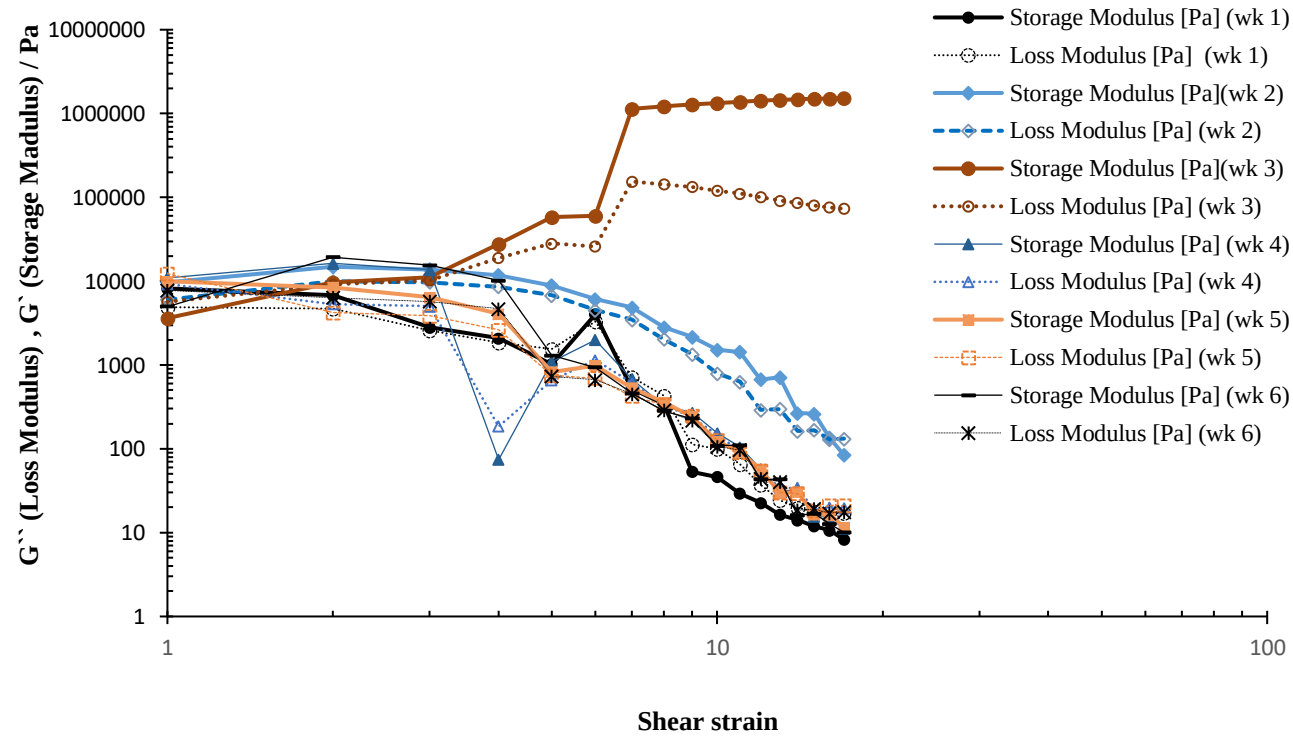


Fig.3 Amplitude sweep for F1 (Niche Extra Dark Chocolate) during a six-week storage period

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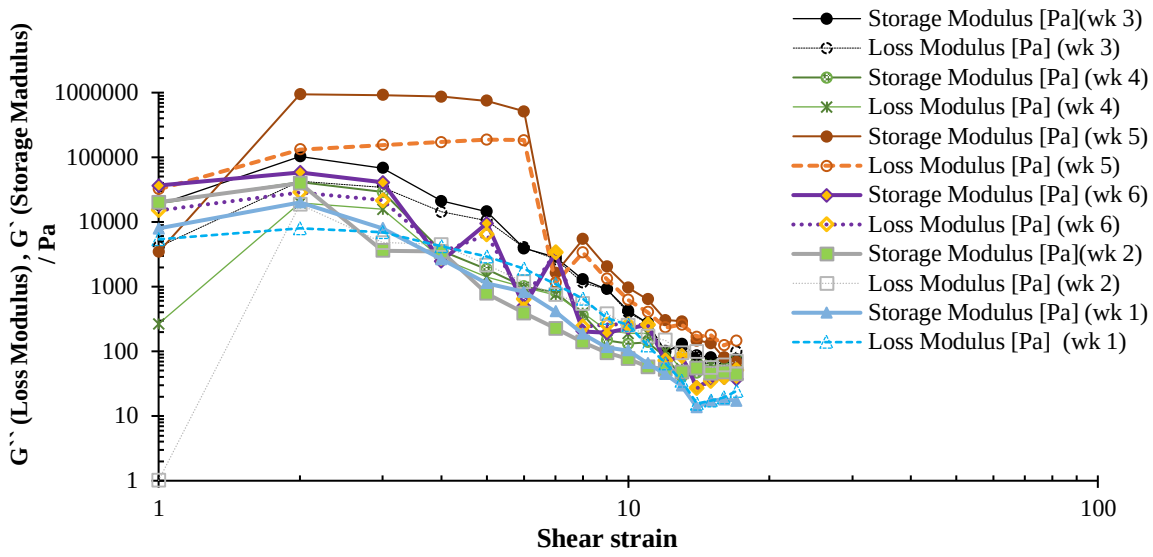


Fig. 4 Amplitude sweep for G1 (Niche Peanut Chocolate Spread) during a six-week storage period

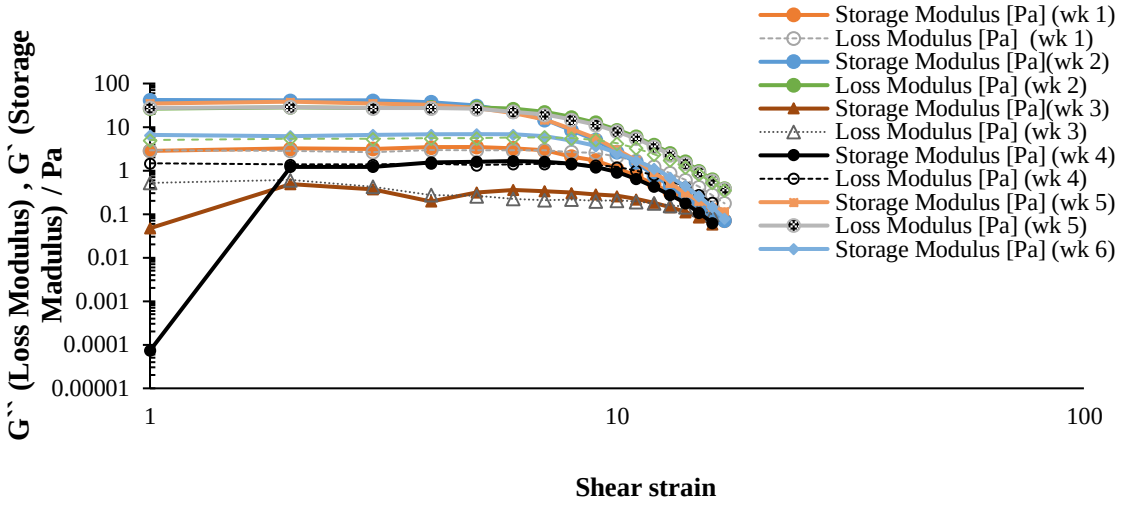


Fig. 5 Amplitude sweep for H1 (Niche Chocolate Drink) during a six-week storage period

Frequency Sweep Behaviour

Frequency sweep tests were conducted to evaluate the time-dependent viscoelastic behaviour of the samples across angular frequencies. The storage modulus (G′) and loss modulus (G″) provide information on the elastic and viscous responses of the samples under small deformation.

The frequency sweep results showed that the samples did not follow one common viscoelastic pattern (Fig. 6–13). In some samples and storage weeks, G′ was higher than G″, showing a more elastic response. In other cases, G″ was close to or higher than G′, showing a stronger viscous response. This indicates that the samples differed in their structural response during storage. The chocolate samples showed measurable viscoelastic properties across the tested frequency range. This may be due to the presence of solid particles dispersed in a fat phase, where interactions among cocoa solids, sugar, milk solids, emulsifiers, and fat crystals affect the elastic and viscous behaviour. Cocoa butter behaved differently from the chocolate products because it is mainly a fat phase and does not contain the same level of dispersed cocoa solids. Its response is therefore more dependent on fat crystallisation and fat crystal rearrangement during storage.

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Some curves showed sharper changes at higher angular frequencies, especially above about 10 rad/s. This suggests that the structure of some samples became less stable under faster deformation. The chocolate drink and some spread samples showed greater variation in G′ and G″, indicating weaker or less uniform structures compared with the solid chocolate samples. These observations agree with the general understanding that fat phase behaviour, particle distribution, and ingredient composition influence the rheological properties of chocolate and cocoa-based systems (Servais, Ranc and Roberts, 2003; Afoakwa, Paterson and Fowler, 2008; De Graef et al., 2011).

The frequency sweep results can also be compared with studies on cocoa butter crystallisation and polymorphism. Stable cocoa butter crystal forms are associated with desirable texture, gloss and physical stability, while changes in crystal form during storage may contribute to structural changes and fat bloom (Balcázar-Zumaeta et al., 2026). Although cocoa butter polymorphism was not directly measured in this study, the differences in G′ and G″ show that the products responded differently to small deformation during storage. This supports the view that storage behaviour depends on the fat phase, dispersed particles and product matrix.

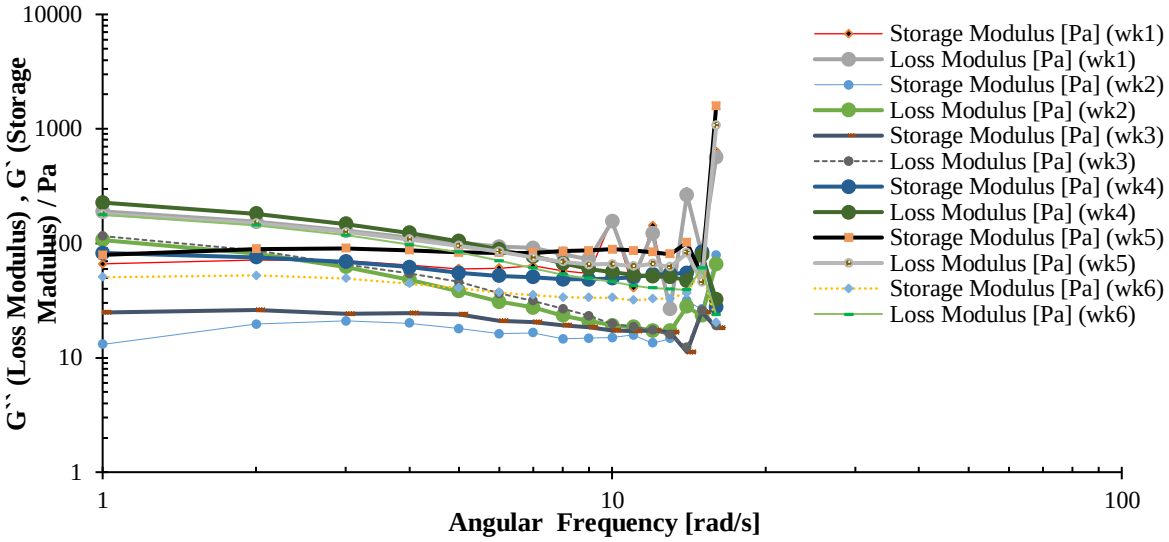


Fig. 6 Frequency sweep for A1 (Natural Cocoa Liquor) during a six-week storage period

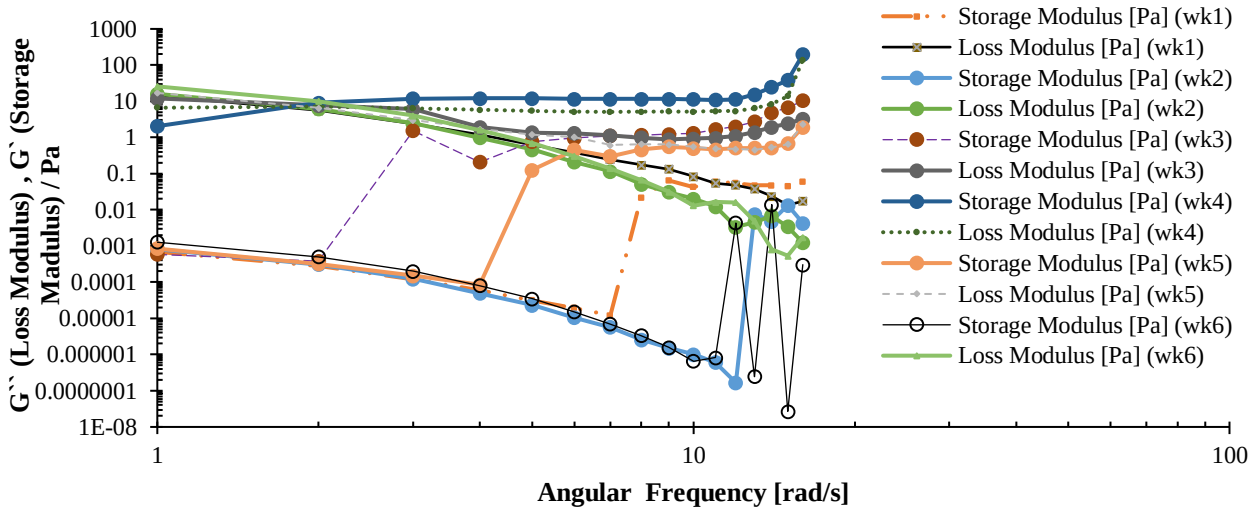


Fig.7 Frequency sweep for B1 (Natural Cocoa Butter) during a six-week period

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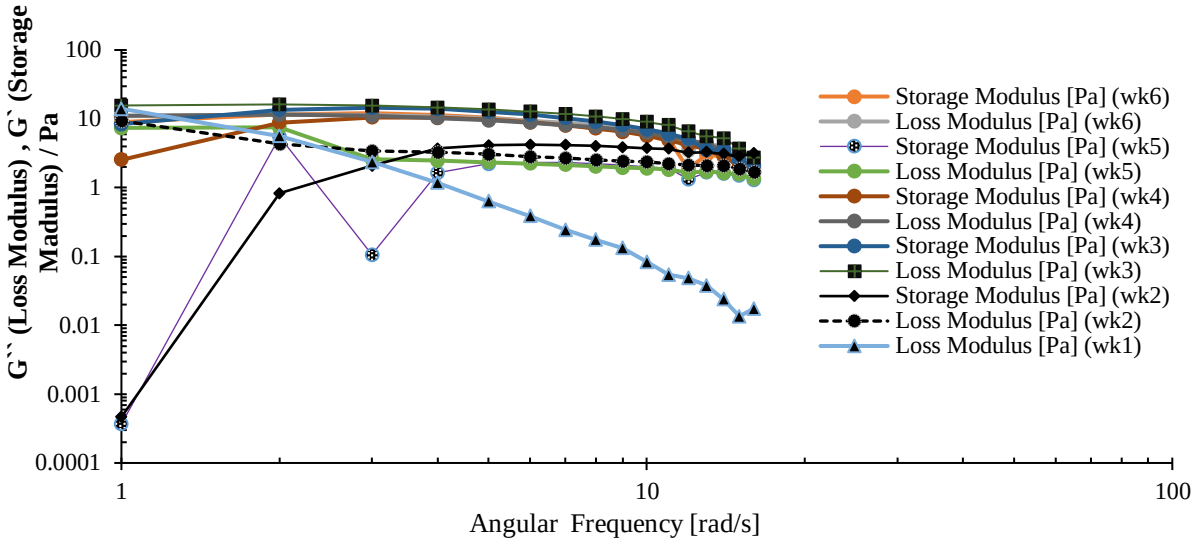


Fig. 8 Frequency sweep for C1 (Natural Cocoa Powder) during a six-week period

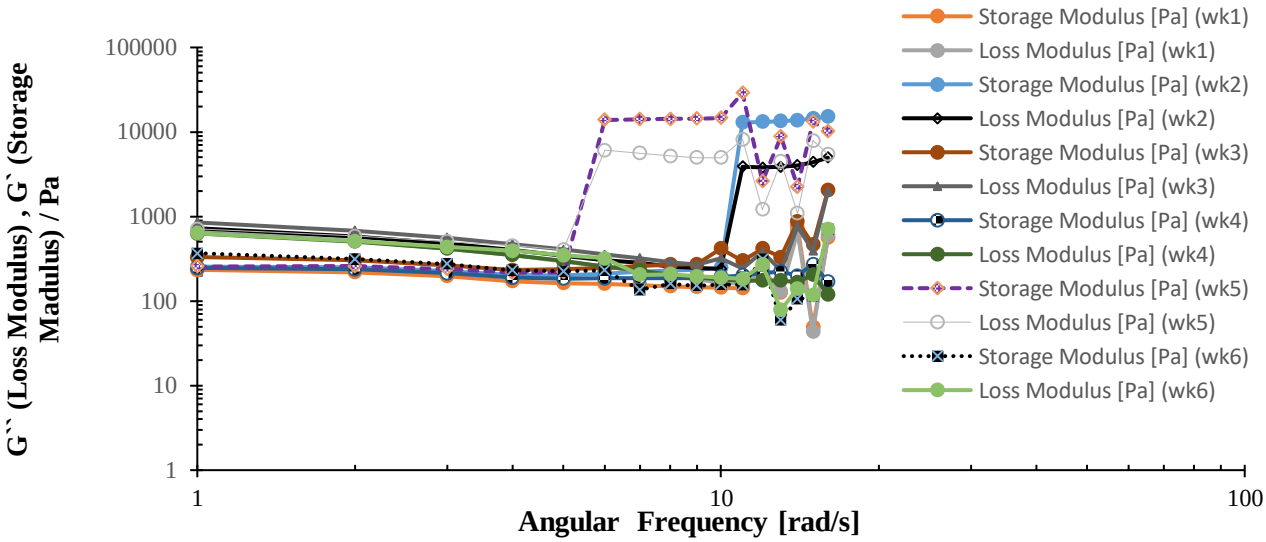


Fig. 9 Frequency sweep for D1 (Niche Milk Chocolate) during a six-week period

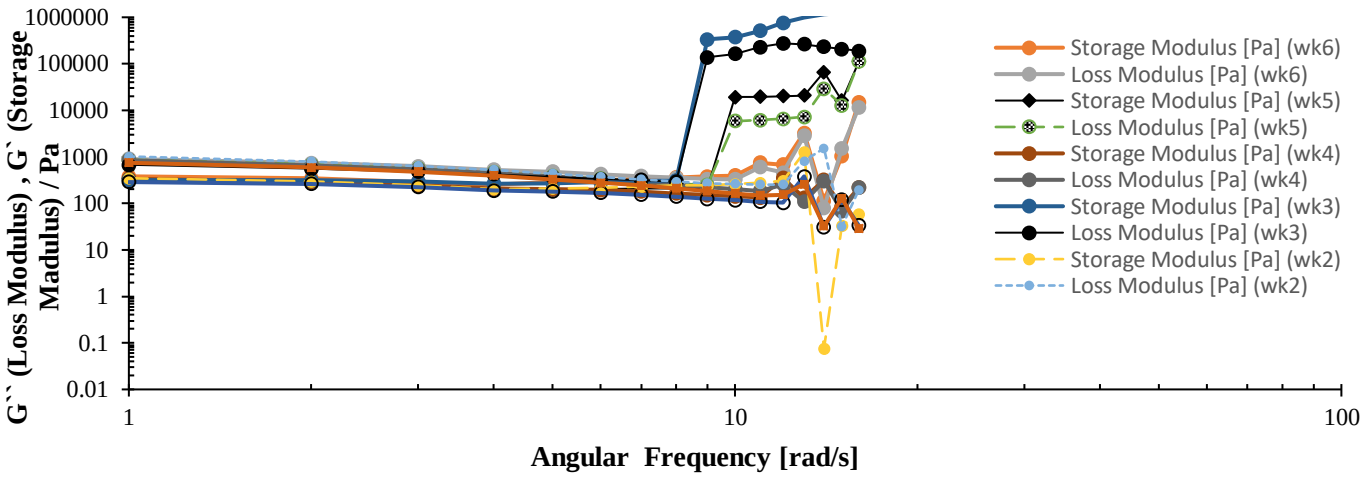


Fig. 10 Frequency sweep for E1 (Niche Dark Chocolate) during six weeks

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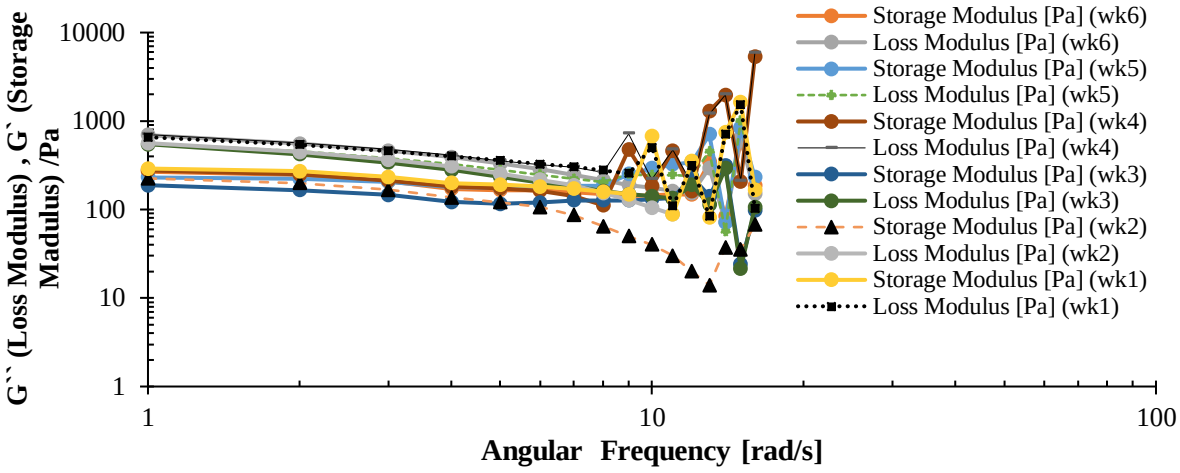


Fig. 11 Frequency sweep for F1 (Niche Extra Dark Chocolate) during a six-week period

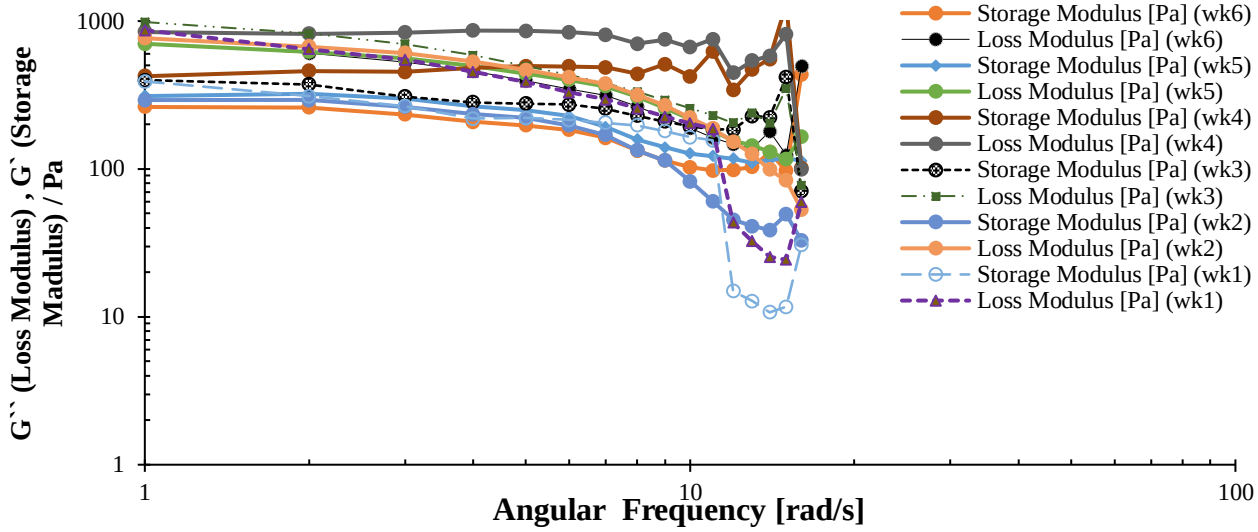


Fig.12 Frequency sweep for G1 (Niche Peanut Chocolate Spread) during a six-week period

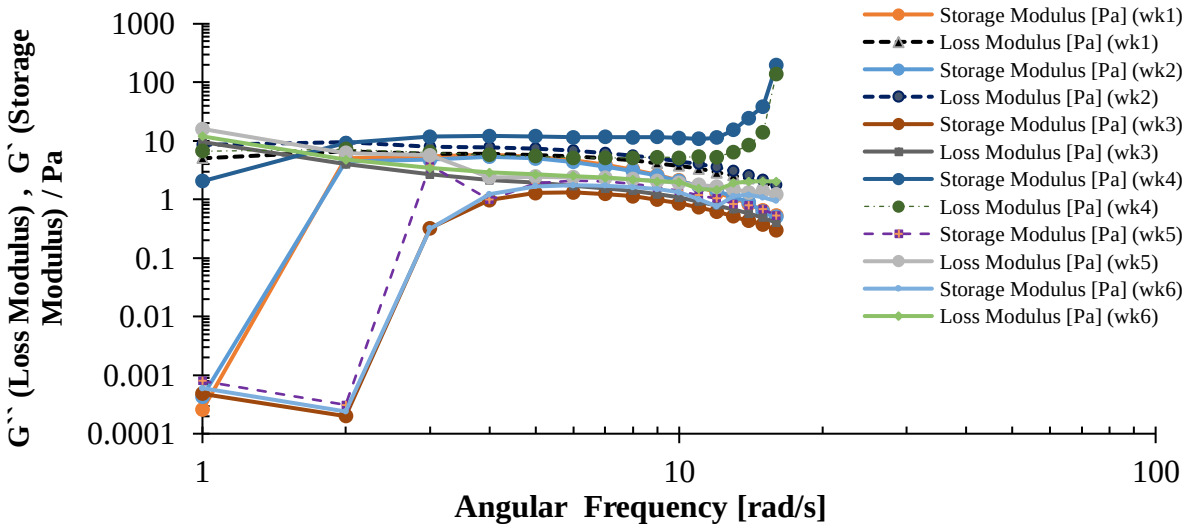


Fig.13 Frequency sweep for H1 (Niche Chocolate Drink) during a six-week period

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Viscosity Characteristics

Viscosity measurements were available for A1, B1, C1, G1, and H1; therefore, the viscosity discussion was limited to these samples. The viscosity curves showed that apparent viscosity decreased as shear rate increased (Fig. 14–18). This indicates shear-thinning behaviour, which is common in cocoa and chocolate systems.

Natural cocoa liquor showed the highest viscosity range, decreasing from about 10^7 to 10^4 mPa·s as shear rate increased. This may be due to its high cocoa solid content and concentrated suspended structure. Niche peanut chocolate spread also showed high viscosity values, probably due to interactions among cocoa solids, peanut particles, sugar, and fat within the product matrix. Natural cocoa powder and Niche chocolate drink showed lower viscosity values compared with cocoa liquor and chocolate spread. Natural cocoa butter showed the lowest viscosity range among the fat-based samples, which is expected because it is mainly a fat phase and contains fewer dispersed solid particles.

The reduction in viscosity with increasing shear rate suggests that particle interactions and weak internal structures were disrupted during shearing, allowing the samples to flow more easily. This behaviour is consistent with chocolate and cocoa-based suspensions, where particle size distribution, fat content, and emulsifier content affect flow properties (Afoakwa, Paterson and Fowler, 2008). Servais, Ranc and Roberts (2003) also reported that chocolate viscosity depends strongly on measurement conditions, shear rate, and sample composition.

For samples with viscosity data across several storage weeks, especially G1 and H1, the curves changed during storage. These changes may be linked to fat phase rearrangement, particle interactions, moisture movement, or partial separation of components. The shear-thinning behaviour observed in the present study agrees with earlier reports that chocolate and cocoa-based suspensions become easier to flow when weak internal structures are disrupted under increasing shear (Afoakwa, Paterson and Fowler, 2008; Servais, Ranc and Roberts, 2003).

The high viscosity of cocoa liquor and peanut chocolate spread may be related to their higher solid content and more concentrated structure, while the lower viscosity of cocoa butter reflects its fat-dominant composition. However, the possible mechanisms were not directly measured and should be confirmed in future studies. The viscosity results show that the tested samples had non-Newtonian shear-thinning behaviour.

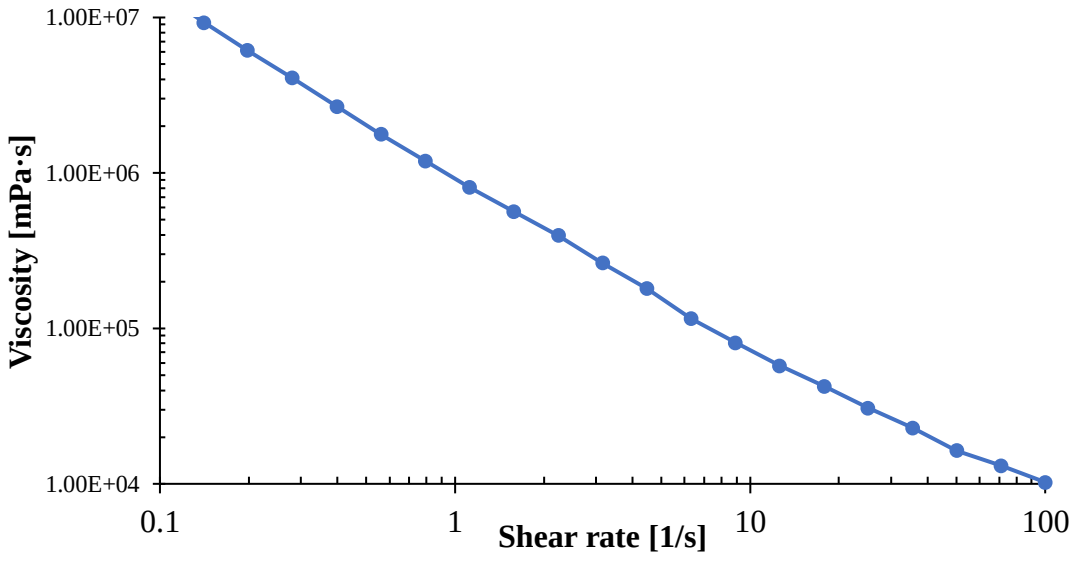


Fig.14 Viscosity curve for A1 (Natural Cocoa Liquor) for week one

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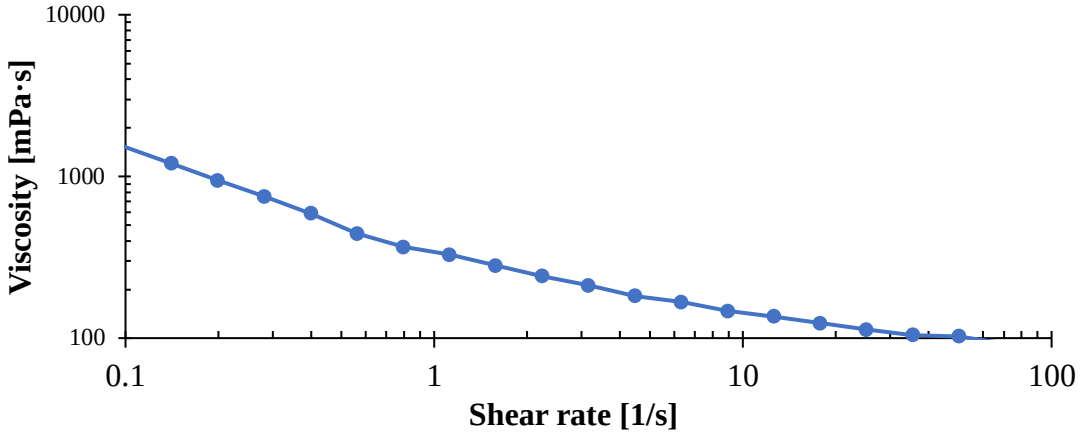


Fig.15 Viscosity curve for B1 (Natural Cocoa Butter) for week one

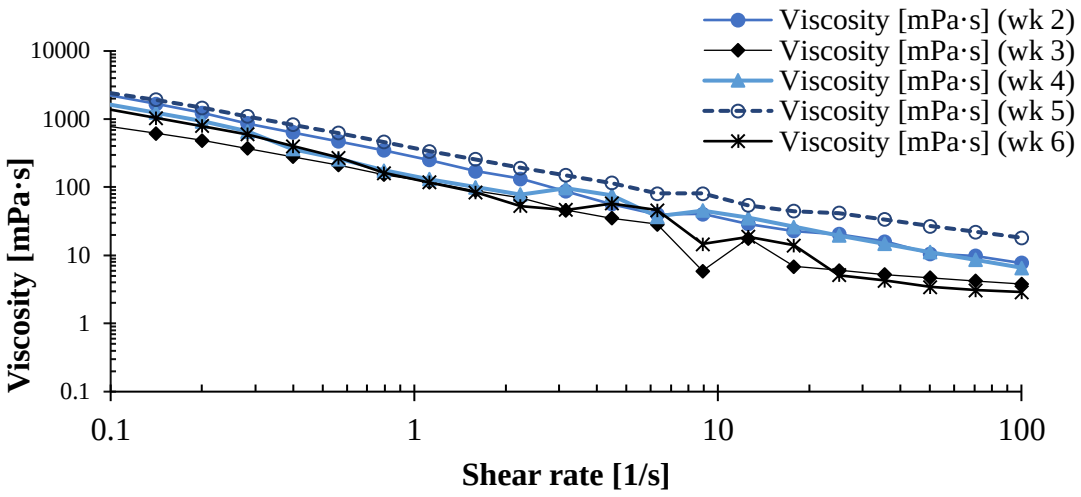


Fig.16 Viscosity curve for C1 (Natural Cocoa Powder) for a six-week period

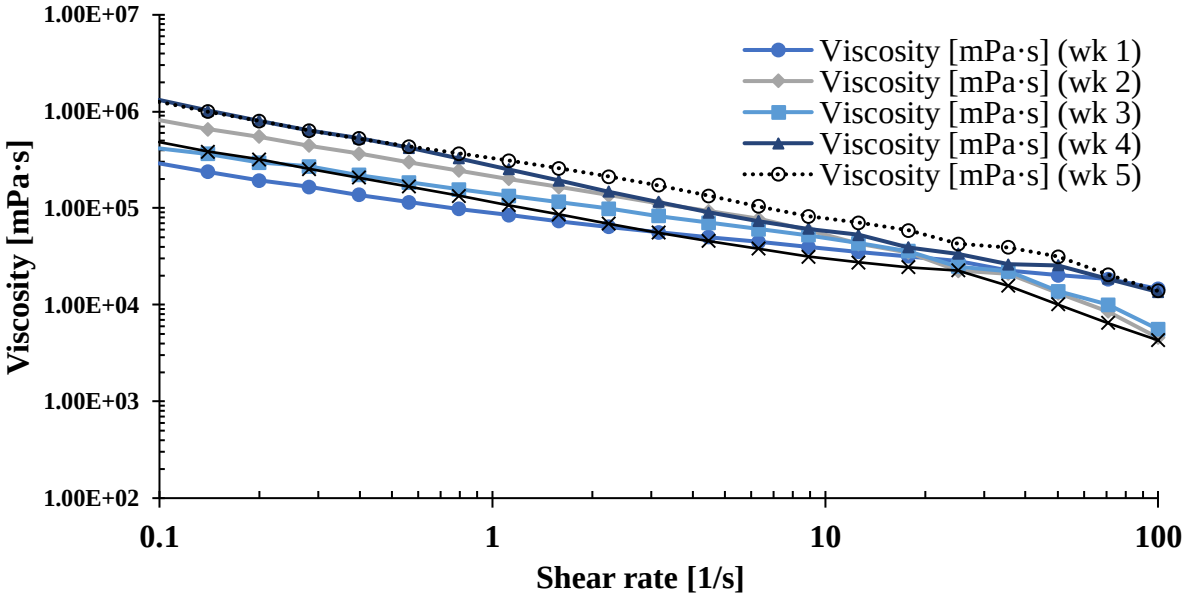


Fig.17 Viscosity curve for G1 (Natural Peanut Chocolate Spread) for a six-week period

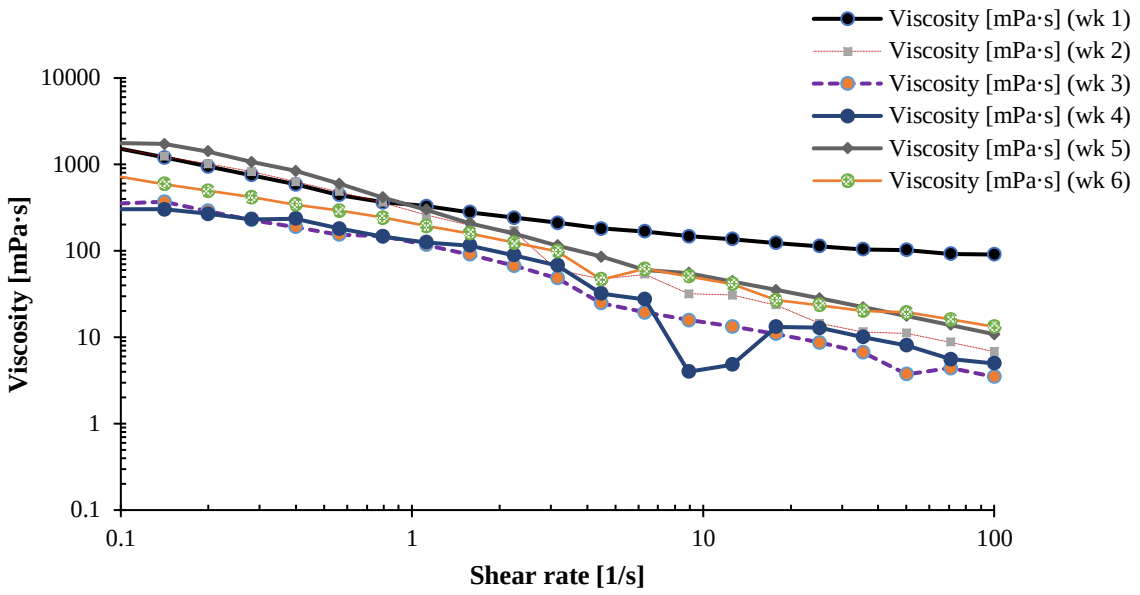


Fig.18 Viscosity curve for H1 (Natural Chocolate Drink) for a six-week period

Relationship Between Colour and Rheological Behaviour

When the colour and rheological results are considered together, the changes observed during storage suggest that both visual quality and flow behaviour were affected by product composition. Products with higher cocoa solid content remained darker, while cocoa butter had higher L* values because of its fat-rich composition. The rheological results also showed that products with more dispersed solids, such as cocoa liquor, chocolate samples, and peanut chocolate spread, had stronger structural responses than the chocolate drink.

These findings agree with previous studies showing that the physical behaviour of chocolate is controlled by the fat phase and the dispersed solid phase. Afoakwa, Paterson and Fowler (2008) reported that particle size distribution, fat content and lecithin content affect the rheological properties of dark chocolate. Balcázar-Zumaeta et al. (2026) also showed that cocoa butter fatty acid and triglyceride composition influence crystallisation, polymorphic transition, texture, gloss and rheology. In the present study, the differences among the products can therefore be explained by their different matrices. Cocoa butter behaved as a fat-rich sample, chocolate samples behaved as concentrated fat-based suspensions, peanut chocolate spread behaved as a semi-solid matrix with added peanut particles, and chocolate drink showed a weaker structure. The colour changes may be related to fat crystallisation, surface changes, oxidation, moisture movement, and particle rearrangement during storage. These same factors may also affect G′, G″, and viscosity. In chocolate products, changes in fat crystal structure may contribute to both rheological changes and surface colour changes. Fat bloom, which is linked to fat migration and cocoa butter crystallisation, can affect the appearance of chocolate during storage (Lonchampt and Hartel, 2004). Storage-related changes in texture and polymorphic stability have also been reported in dark chocolate (Nightingale, Lee and Engeseth, 2011).

The results show that colour and rheological behaviour differed among the cocoa-based products during storage. This difference was likely due to variations in fat content, cocoa solid content, particle distribution, and product form. The findings suggest that cocoa liquor, cocoa butter, cocoa powder, chocolate bars, chocolate spread, and chocolate drink should be considered separately when assessing storage stability and quality control.

CONCLUSION

This study investigated the colour and rheological properties of eight cocoa and chocolate products during a

six-week storage period at 25 °C. The results showed that the products differed in their colour and flow behaviour during storage. Cocoa liquor, cocoa powder, milk chocolate, dark chocolate, extra dark chocolate, peanut chocolate spread, and chocolate drink maintained generally dark colour values, while cocoa butter remained lighter because of its low non-fat cocoa solid content.

The colour parameters changed during storage, indicating that storage time affected the measured colour characteristics of the products. These changes may be related to differences in fat content, cocoa solid content, particle distribution, and product form. The rheological results also showed that the samples responded differently to shear and deformation. Cocoa liquor, cocoa butter, cocoa powder, peanut chocolate spread, and chocolate drink showed shear-thinning behaviour, with viscosity decreasing as shear rate increased. The amplitude and frequency sweep results showed differences in storage modulus and loss modulus, indicating that the elastic and viscous properties of the products varied with product type and storage time.

The main finding from this study is that cocoa and chocolate products do not respond to storage in the same way. Their stability may be influenced by composition, fat phase behaviour, solid particle distribution, and physical form. This information is useful for quality control because it can help processors identify products that may require stricter storage control, improved packaging, or formulation adjustment. The findings can also support process control and technology transfer for cocoa processors by providing information on how selected cocoa-derived products behave during controlled storage at 25 °C.

Data availability

The data supporting the findings of this study are available within the article.

Competing Interests

The authors have no competing interests to declare that are relevant to the content of this article.

Funding

Not applicable.

Credit Author Statement

G.N-A.M. and J.K.A.: Conceptualization; G.N-A.M.: Investigation; G.N-A.M, M.A.D.R. and J.K.A Methodology; M.A.D.R. and J.K.A: Resources; J.K.A.: Supervision; G.N-A.M: Writing - original draft; M.A.D.R. and J.K.A.: Writing - review and editing. All authors reviewed the manuscript.

AI Declaration

The entire text was written by the authors. Grammarly was only used to correct grammar, spelling, typographical errors and improve basic clarity.

REFERENCES

1. Afoakwa, E.O., Paterson, A. and Fowler, M. (2007) ‘Factors influencing rheological and textural qualities in chocolate – a review’, Trends in Food Science & Technology, 18(6), pp. 290–298. doi: 10.1016/j.tifs.2007.02.002.
2. Afoakwa, E.O., Paterson, A. and Fowler, M. (2008) ‘Effects of particle size distribution and composition on rheological properties of dark chocolate’, European Food Research and Technology, 226, pp. 1259–1268. doi: 10.1007/s00217-007-0652-6.
3. Balcázar-Zumaeta, C.R., Chagas-Júnior, G.C.A., Ferreira, N.R., Pinheiro, W.B.D.S., Maicelo-Quintana, J.L., Cayo-Colca, I.S. and Castro-Alayo, E.M. (2026) ‘Advances in cocoa butter and

alternative fats: composition and crystallization dynamics in chocolate production', European Food Research and Technology, 252, 107. doi: 10.1007/s00217-026-05046-3

4. Bahari, A. and Akoh, C.C. (2018) 'Texture, rheology and fat bloom study of "chocolates" made from cocoa butter equivalent synthesized from illipe butter and palm mid-fraction', LWT - Food Science and Technology, 97, pp. 349–354. doi: 10.1016/j.lwt.2018.07.013.
5. Beckett, S.T. (2009) Industrial Chocolate Manufacture and Use. 4th edn. Oxford: Wiley-Blackwell.
6. Chandra, S., Ravikrishnan, V., Paranthaman, R., & Moses, J. A. (2026). Crystallization kinetics and quality evolution in thermally cycled chocolates. Journal of Food Measurement and Characterization, 20, 5043–5057. https://doi.org/10.1007/s11694-025-03981-5
7. Chi, J., Hou, L., Wang, L., & Wang, X. (2025). Evaluation methods of crystal behaviors and structures of symmetrical monounsaturated triacylglycerols. Journal of Texture Studies, 56(3), e70023. https://doi.org/10.1111/jtxs.70023
8. De Graef, V., Depypere, F., Minnaert, M. and Dewettinck, K. (2011) 'Chocolate yield stress as measured by oscillatory rheology', Food Research International, 44(9), pp. 2660–2665. doi: 10.1016/j.foodres.2011.05.009.
9. Dias, J., Panda, A., Partidário, A., Alvarenga, N., Lita da Silva, J., Cordeiro, T., & Prazeres, P. (2022). Impact of geographical origin on chocolate microstructure, phase transition, and fat bloom. In Charis M. Galanakis (Ed.), Trends in Sustainable Chocolate Production (pp. 153–187). Springer. https://doi.org/10.1007/978-3-030-90169-1_5
10. Eischen, J.C. and Windhab, E.J. (2002) 'Viscosity of cocoa and chocolate products', Applied Rheology, 12(1), pp. 32–34. doi: 10.1515/arh-2002-0020.
11. Hendrik, N. J., Marchesini, F. H., Van de Walle, D., & Dewettinck, K. (2023). Chocolate tempering in a rheometer: Monitoring rheological properties during and after crystallization of cocoa butter. Food Analytical Methods, 16(9–10), 1555–1570. https://doi.org/10.1007/s12161-023-02522-4
12. Kpodo, F. M., Adzinyo, O. A., Agbenorhevi, J. K., Hattoh, D. P., Dzieketey, R. K., Amanttesse, S. and Agbosoo, B. D. (2026). Physicochemical, Rheological, and Sensory Properties of Tomato Ketchup Stabilized by Thickener Blends. Journal of Food Processing and Preservation, 2026(1), 5174738. https://doi.org/10.1155/jfpp/5174738
13. Lonchampt, P. and Hartel, R.W. (2004) 'Fat bloom in chocolate and compound coatings', European Journal of Lipid Science and Technology, 106(4), pp. 241–274. doi: 10.1002/ejlt.200400938.
14. Medina-Mendoza, M., Rodriguez-Pérez, R.J., Rojas-Ocampo, E., Torrejón-Valqui, L., Fernández-Jeri, A.B., Idrogo-Vásquez, G., Cayo-Colca, I.S. and Castro-Alayo, E.M. (2021) 'Rheological, bioactive properties and sensory preferences of dark chocolates with partial incorporation of Sacha Inchi (Plukenetia volubilis L.) oil', Heliyon, 7(2), e06154. doi: 10.1016/j.heliyon.2021.e06154.
15. Motamayor, J.C., Lachenaud, P., da Silva e Mota, J.W., Loor, R., Kuhn, D.N., Brown, J.S. and Schnell, R.J. (2008) 'Geographic and genetic population differentiation of the Amazonian chocolate tree (Theobroma cacao L.)', PLOS ONE, 3(10), e3311. doi: 10.1371/journal.pone.0003311.
16. Nightingale, L.M., Lee, S.-Y. and Engeseth, N.J. (2011) 'Impact of storage on dark chocolate: texture and polymorphic changes', Journal of Food Science, 76(1), pp. C142–C153. doi: 10.1111/j.1750-3841.2010.01970.x.
17. Pastor, C., Santamaría, J., Chiralt, A. and Aguilera, J.M. (2007) 'Gloss and colour of dark chocolate during storage', Food Science and Technology International, 13(1), pp. 27–34. doi: 10.1177/1082013207075664.
18. Servais, C., Ranc, H. and Roberts, I.D. (2003) 'Determination of chocolate viscosity', Journal of Texture Studies, 34(5–6), pp. 467–497. doi: 10.1111/j.1745-4603.2003.tb01077.x.
19. Suri, T., & Basu, S. (2022). Heat resistant chocolate development for subtropical and tropical climates: A review. Critical Reviews in Food Science and Nutrition, 62(20), 5603–5622. https://doi.org/10.1080/10408398.2021.1888690
20. Szydłowska-Czerniak, A., Rabiej, D., & Pawłowicz, R. (2017). Comparison of the crystallization behaviors of different types of cocoa butters and chocolates. Journal of Food Processing and Preservation, 41(2), e13154. https://doi.org/10.1111/jfpp.13154
21. Yucel, E., Sivri, G. T., Palabiyik, I., & Tasan, M. (2022). A rheometer-based method to determine the crystal types of cocoa butter in white chocolate. European Food Research and Technology, 248(6), 1635–1644. https://doi.org/10.1007/s00217-022-03991-3