Advances in Life Sciences 2025, 13(1): 1-8
DOI: 10.5923/j.als.20251301.01

Processing and Rheological Behavior of Sudanese Mango Cultivars under Vacuum Concentration

Fatima Mohi eldin Mohammed Ahmed[1], Fatima Fadul Ali[2], Najlaa Siddig Nasir[3], Waheeba E. Ahmed[4], Ammar AL-Farga[5], Islam Ragab[6,*]

[1]Dept. of Food Science and Technology, College of Agriculture, Al-zaiem Al-azhari University-Khartoum, Sudan
[2]Dept. of Health Education and Promotion, College of Public Health, Al-zaiem Al-azhari University-Khartoum, Sudan
[3]Dept. of Medical Entomology, College of Health, Al-zaiem Al-azhari University-Khartoum, Sudan
[4]Department of Food Science and Human Nutrition, College of Agriculture and Food, Qassim University, Buraydah, Saudi Arabia
[5]Department of Biochemistry, Faculty of Science, University of Jeddah, Saudi Arabia
[6]Department of Chemistry, College of Science, Qassim University, Buraidah, Saudi Arabia

Abstract **Background:** The success of mango cultivation in Sudan can be attributed to the potential for extending the fruiting season to eleven months a year, thanks to diverse environmental conditions. This presents Sudan with a significant opportunity for export in the global market. Mango pulp, characterized by its high moisture content, is highly perishable and has a short shelf life. Both marketers and consumers desire an extended shelf life, necessitating the concentration of the pulp. **This study** aimed to evaluate the impact of vacuum concentration on the physicochemical and rheological properties of mango pulp and its concentrates. **Methods:** The physicochemical and rheological properties of four mango cultivars (Kitchener, Alphonso, Shendi, and Neelum) were analyzed before and after processing. These cultivars were concentrated under vacuum using a closed kettle pan at a temperature of 50 ℃ and a pressure of 24 inches Hg. The resulting concentrates were 26%, 26%, 26%, and 22%, respectively. Rheological parameters were measured using a rheometer at 30 ℃ and a shear stress range of (0-1000 s^{-1}). The Bingham model was employed to determine the relationship between shear stress and shear rate. **Results:** The analysis of physicochemical and rheological properties, conducted both before and after processing, revealed significantly higher values of total soluble solids (TSS), viscosity, and total sugars. Furthermore, there were notable differences in rheological parameters, such as yield stress, consistency coefficient, and behavior index, among the different mango varieties. **Conclusion:** Kitchener and Neelum mango concentrates exhibited thixotropic behavior with yield stress. In contrast, Alphonso concentrate demonstrated a mixed behavior of pseudoplastic and thixotropic characteristics. Shendi concentrate displayed pseudoplastic behavior with yield stress. **Recommendation:** It is advised to apply physical treatments to Kitchener and Neelum mango concentrates to reduce fiber content, thereby enhancing heat transfer and improving pumping characteristics.

Keywords Mango, Pulp, Concentrate, Physiochemical properties, Rheological properties

1. Introduction

Mango is one of the most significant tropical fruit trees globally, renowned for its high yield, consumption, and exceptional nutritional value. It is rich in bioactive compounds such as vitamin C, carotenoids, and polyphenols, which contribute to its antioxidant activity [1]. Mango fruit have attractive color, pleasant aroma and taste . Fruit pulp and concentrate play a crucial role in health. They are dietary sources of essential nutrients, micronutrients, and vitamins, which are vital for human health and well-being. A well-balanced diet rich in fruits is particularly valuable for its ability to prevent deficiency diseases and has been reported to reduce the risk of several other diseases [2]. Mango (Mangifera indica L) is commonly cultivated in mainly tropical and subtropical regions and is Worldwide distributed [3]. It belongs to the family Anacardiaceae and the genus Mangifera [4,5]. It has been cultivated for more than 4,000 years [6]. Mango provides an excellent flavor, attractive odor and delicious taste [7] it also has high nutritional value [8]. The physico-chemical characteristics of mango fruits and the technological qualities of their processed products vary among different mango varieties, with some being more suitable than others for specific applications [9]. Mango processing can solve the problem of accumulation of fresh mango fruits and it is highly perishable and has a short shelf life [10,11]. Concentrating the juice through evaporation reduces transportation costs and extends shelf life by achieving high Brix levels. [12].

* Corresponding author:
is.mohamed@qu.edu.sa (Islam Ragab)
Received: Sep. 29, 2025; Accepted: Oct. 21, 2025; Published: Oct. 25, 2025
Published online at http://journal.sapub.org/als

Physical properties, such as density and viscosity, are influenced by the solid content and temperature of mango products. Therefore, it is essential to understand these physical properties as a function of temperature and solid content during the manufacturing process to ensure excellent quality. Developing a comprehensive database of these values is crucial for optimizing the transformation process [13]. Rheology is the science that studies the deformation and flow behavior of matter. The consistency of a Newtonian fluid, such as water, milk, or clear fruit juice, can be described by its viscosity. However, the viscosity of a non-Newtonian fluid changes with varying shear rates and therefore must be characterized by multiple parameters [14]. Numerous studies have been conducted to determine the rheological properties of fruit purees, fruit juices, vegetable purees, and vegetable suspensions [15].

The viscosity characteristics of food products significantly impact various aspects of fluid performance during processing [16,17], such as pumpability, droplet breakup in spray drying, emulsion formation, flow into molds, and formability. Additionally, viscosity affects the quality of liquid products, including texture, flavor release, stability, and appearance. Viscosity is correlated with composition and molecular distribution, thereby influencing the material's overall characteristics [18].

The rheological behavior of fruit juices and pulps is significantly influenced by their quantitative and qualitative composition, which depends on the fruit type and the treatments applied during the manufacturing process. Factors influencing the rheological behavior of fruit pulps encompass temperature, total solids, concentration, and particle size [19]. The inclusion of pulp solids in the dispersed phase of fruit juice contributes to its non-Newtonian characteristics [20].

The rheological properties of fruit juice are crucial for quality control, designing process engineering applications, and selecting appropriate equipment such as heat exchangers, transport systems, evaporators, and pumps. They also play a vital role in calculating energy usage and power requirements for mixing, determining flow in processing operations like pasteurization, concentration, dehydration, aseptic processing, and ensuring consumer acceptability of the product [21-23]. The rheological behavior of fruit juices and concentrates can be characterized by various rheological models, depending on the specific nature of the juices [21]. Various rheological models have been employed to describe the flow behavior of food, including the Newtonian model (one parameter), the power law model (two parameters), the Bingham and Casson models (two parameters), and the Herschel-Bulkley model (three parameters) [24]. These models effectively characterize the rheological behavior of various fruit juices [21].

Therefore, this study aimed to evaluate the effect of vacuum concentration on the physicochemical and rheological properties of pulp and concentrates from four Sudanese mango cultivars (Kitchener, Alphonso, Shendi, and Neelum). The specific objectives were to determine the changes in key quality parameters—including total soluble solids, acidity, pH, sugars, ascorbic acid, non-enzymatic browning, density, and viscosity—before and after processing, and to characterize the flow behavior using the Herschel-Bulkley model.

2. Material and Methods

Experiments were conducted at canning section in Food Research Center Shambat, unit operation laboratory of university of Khartoum department of chemical engineering and Central Petroleum Laboratories in Ministry of petroleum, Sudanese petroleum Corporation.

2.1. Preparation of Raw Materials

Ripe mango fruits from four cultivars (Kitchener, Alphonso, Shendi, and Neelum) were sourced from local orchards in the Gezira and Khartoum states of Sudan during the peak harvest season (June to August 2023). The fruits were selected at a commercially ripe stage based on their skin color, firmness, and aroma. The selection criteria ensured that the fruits were free from visual defects, mechanical injuries, and fungal infections. Upon receipt at the laboratory of the Food Research Center, Shambat, the fruits were sorted, washed, peeled, and sliced with a stainless-steel knife before being pulped using a fruit pulper. The extract pulp of four varieties (Kitchener, Alphonso, Shendi and Neelum) were heated at 80 ℃ in jacketed kettle for 10 minutes [25,26] with continuous stirring. After pasteurization, the samples were quickly cooled to room temperature in ice water.

2.2. Vacuum Concentration

The concentration process was performed under vacuum using a jacketed kettle pan (Pilsen, 10 L capacity, stainless steel). The process was carried out at 50 ℃ and an absolute pressure of 24 inches of Mercury (inch Hg), which is equivalent to approximately 61 kPa **or** 0.61 bar. This level of vacuum was maintained using a vacuum pump [25,26]. The pan was heated using water bath connected to thermostat and pump. After process was stopped, the physiochemical characteristics were evaluated.

2.3. Physiochemical Analysis

TSS, PH, Total sugars, and Ascorbic acid content of the mango pulp and concentrates were determined according to AOAC [27]. The total titratable acidity was determined using the method outlined by [28].

2.4. Non Enzymatic Browning

The method commonly applied to evaluate non–enzymatic browning is generally known as "soluble color". Non-enzymatic browning was determined using spectrophotometric method [29]. 10 grams of sample were extracted with 100 ml ethanol (60%) for 12 hours and centrifuged at 1260 rpm for 5 minutes. The absorbance of the extract was then measured with spectrophotometer (model: uv-1800.Shimadzu) at 420 nm with 60% ethanol as blank.

2.5. An Apparent Viscosity

The apparent viscosity of mango pulp and concentrates was measured using a concentric cylinder Brookfield rheometer (DV-III ULTRA; Brookfield Engineering Laboratories, USA). A Brookfield (TC-502) thermostatic bath was utilized to adjust the sample temperature to 30 ℃ for each test. The filled sample cup (10 ml) and spindle (LV4) were equilibrated at this temperature for approximately 20 minutes [19]. The apparent viscosity data were obtained using Rheocalc software (version V3.3 build 49-1; Brookfield Engineering Laboratories, MA, USA) at 50 rpm. The averages of ten readings were recorded for each material.

2.6. Density of Mango Pulp and Concentrates

The density of mango pulp and concentrates were determined by digital density meter (Model DMA 5000, ANTON PAAR). According to D4052-96. American National standard method. A small volume of approximately 0.7 ml of the liquid sample was introduced into an oscillating sample tube. The change in oscillating frequency, caused by the alteration in the tube's mass, was used alongside calibration data to determine the sample's density.

2.7. Rheological Parameter of Mango Pulp and Concentrates

The rheological measurements were performed in controlled rate using rheometer (Hakke Rheoscope1, Karlsruhe, Germany). Shear stress/rate rotation Ram tests were performed using a cone sensor (C70/10 Tipo; 70mm diameter, 1angle) with 0.026 mm gap and measuring plate cover (MPC70). The sample compartment was controlled at temperature of 30 ℃ Cousin Cryostat /Circulator (Haake Phoenix II P1) ascending and descending flow cruve of shear stress versus shear rate were carried out in the range (0-1000s-1) during 300s. Mathematical model of Bingham was used to calculate the relationship between shear stress and shear rate.

3. Statistical Analyses

Data generated was subject to statistical analysis (SAS) (2007). A completely randomized design (CRD) was adopted for this study. Analysis of variance and the least significant difference (LSD at 5%) were used to separate the means according to Duncan's Multiple Range Test (DMRT) [30].

4. Results

4.1. Effect of Vacuum Concentration on the Physicochemical Properties of Mango Pulp

The impact of vacuum concentration on the physicochemical properties of the mango pulp blends is summarized in Tables 1 and 2. The concentration process led to significant increases ($p \leq 0.05$) in total soluble solids (TSS), total sugars, reducing sugars, non-reducing sugars, ascorbic acid content, and apparent viscosity compared to the fresh pulp. Conversely, no significant differences ($p > 0.05$) were observed in titratable acidity, pH, non-enzymatic browning, or density at 30 ℃ after concentration.

4.2. Effect of Mango Cultivar on the Physicochemical Properties of Concentrates

Significant variations ($p \leq 0.05$) were observed in all measured physicochemical properties among the four mango cultivars after concentration, as detailed in Tables 3 and 4. The Kitchener cultivar exhibited the highest values for total sugars (16.03%), titratable acidity (0.39%), and ascorbic acid (35.07 mg/100g). In contrast, the Shendi concentrate showed the highest pH (4.61), density at 25 ℃ and 30 ℃, and the highest viscosity (4206 cP). The Neelum cultivar recorded the lowest values for most parameters, including TSS (18.50%), titratable acidity (0.33%), and ascorbic acid (17.24 mg/100g), but exhibited the highest level of non-enzymatic browning.

Table 1. Effect of processing on physicochemical properties of four Sudanese mango varieties*

Treatment	Titratable acidity (%)	Total sugars (%)	Reducing sugars (%)	Non-reducing sugars (%)	pH-value	Total soluble solids (%)
Before concentrate	$0.33^{a} \pm 0.02$	$10.33^{b} \pm 0.15$	$4.05^{b} \pm 0.13$	$5.79^{b} \pm 0.36$	$4.30^{a} \pm 0.61$	$18.00^{b} \pm 0.52$
After concentrate	$0.41^{a} \pm 0.05$	$16.15^{a} \pm 0.19$	$5.22^{a} \pm 0.08$	$10.30^{a} \pm 0.41$	$4.58^{a} \pm 0.67$	$25.00^{a} \pm 0.59$

*Values are presented as mean ± SD. Any two-mean value(s) bearing the same superscript(s) in a column are not significantly different ($P \leq 0.05$).

Table 2. Effect of processing on physicochemical properties of four Sudanese mango varieties*

Treatment	Ascorbic acid (mg/100g)	Non-enzymatic browning	Density at 25 ℃	Density at 30 ℃	Viscosity (cP)
Before concentrate	$18.05^{b} \pm 0.0$	$0.245^{a} \pm 0.0$	$1.074^{a} \pm 0.0$	$1.060^{a} \pm 0.0$	$628.12^{b} \pm 0.0$
After concentrate	$33.17^{a} \pm 0.0$	$0.289^{a} \pm 0.0$	$1.106^{a} \pm 0.0$	$1.102^{a} \pm 0.0$	$6718.86^{a} \pm 0.0$

*Values are presented as mean ± SD. Any two-mean value(s) bearing the same superscript(s) in a column are not significantly different ($P \leq 0.05$).

Table 3. Effect of varieties difference on physicochemical properties of four Sudanese mango varieties*

Varieties	Titratable acidity (%)	Total sugars (%)	Reducing sugars (%)	Non-reducing sugars (%)	pH value	Total soluble solids (%)
Kitchener	0.39^{a} ±0.05	16.03^{a} ±0.21	4.19^{b} ±0.05	11.07^{a} ±0.13	4.30^{d} ±0.02	21.50^{b} ±0.14
Alphonso	0.37^{a} ±0.02	11.67^{c} ±0.15	3.32^{c} ±0.01	7.92^{b} ±0.11	4.45^{b} ±0.05	22.00^{b} ±0.19
Shendi	0.38^{a} ±0.04	15.40^{b} ±0.28	8.62^{a} ±0.07	6.45d ±0.18	4.61^{a} ±0.07	24.00^{a} ±0.25
Neelum	0.33^{b} ±0.01	9.91^{d} ±0.11	2.42^{d} ±0.10	7.09^{c} ±0.06	4.41^{c} ±0.03	18.50^{c} ±0.10

*Values are presented as mean ± SD. Any two-mean value(s) bearing the same superscript(s) in a column are not significantly different (P≤0.05).

Table 4. Effect of varieties difference on physicochemical properties of four Sudanese mango varieties*

Mango Varieties	Ascorbic acid (mg/100g)	Non-enzymatic browning	Density at 25 ℃	Density at 30 ℃	Viscosity (cP)
Kitchener	35.07^{a} ±0.61	0.2975^{b} ±0.03	1.080^{d} ±0.04	1.081^{b} ±0.03	3100.00^{d} ±17.05
Alphonso	30.40^{b} ±0.57	0.2260^{d} ±0.01	1.093^{b} ±0.06	1.078^{c} ±0.02	3663.00^{c} ±18.56
Shendi	19.75^{ac} ±0.41	0.2325^{c} ±0.02	1.101^{a} ±0.07	1.093^{a} ±0.04	4206.00^{a} ±20.78
Neelum	17.24^{d} ±0.33	0.3120^{a} ±0.04	1.085^{c} ±0.05	1.072^{d} ±0.01	4125.00^{b} ±29.31

*Values are presented as mean ± SD. Any two-mean value(s) bearing the same superscript(s) in a column are not significantly different (P≤0.05).

Table 5. Effect of processing and varieties difference on physicochemical properties of Sudanese mango puree before and after concentration*

Mango Varieties	Titratable acidity (%)		Total sugars (%)		Reducing sugars (%)		Non-reducing sugars (%)		pH-value		Total soluble solids (%)	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Kitchener	0.3400^{bcd} ±0.01	0.4503^{a} ±0.00	8.807^{g} ±0.02	23.25^{c} ±0.68	3.187^{d} ±0.01	5.183^{c} ±0.03	5.333^{d} ±0.02	16.81^{a} ±0.09	4.24^{d} ±0.01	4.36^{c} ±0.01	17.00^{c} ±1.00	26.00^{a} ±1.00
Alphonso	0.3300^{cd} ±0.01	0.4167^{ab} ±0.01	10.63^{f} ±0.05	12.69^{d} ±0.04	3.08^{d} ±0.01	3.563^{d} ±0.01	7.17^{c} ±0.04	8.673^{b} ±0.04	4.33^{c} ±0.01	4.57^{b} ±0.01	18.00^{c} ±1.00	26.00^{a} ±1.00
Shendi	0.3533^{bcd} ±0.01	0.4000^{abc} ±0.10	13.80^{b} ±0.07	17.00^{a} ±0.10	7.93^{b} ±0.05	9.300^{a} ±1.20	5.58^{d} ±0.03	7.32^{c} ±1.34	4.55^{b} ±0.01	4.67^{a} ±0.01	22.00^{b} ±1.00	26.00^{a} ±1.00
Neelum	0.2900^{d} ±0.02	0.3622^{bcd} ±0.09	8.093^{h} ±0.03	11.67^{e} ±0.06	2.00^{e} ±0.01	2.83^{d} ±0.00	5.79^{d} ±0.02	8.397^{b} ±0.06	4.09^{e} ±0.01	4.72^{a} ±0.08	15.00^{d} ±1.00	22.00^{b} ±1.00

*Values are presented as mean ± SD. Any two-mean value(s) bearing the same superscript(s) in a column are not significantly different (P≤0.05).

Table 6. Effect of processing and varieties difference on physicochemical properties of Sudanese mango puree before and after concentration*

Mango Varieties	Ascorbic acid (mg/100g)		Optical density		Density in 25 ℃		Density in 30 ℃		Viscosity (cP)	
	Before	After	Before	After	Before	After	Before	After	Before	After
Kitchener	22.93^{c} ±0.46	47.20^{a} ±0.80	0.296^{c} ±0.00	0.299^{b} ±0.00	1.067^{g} ±0.00	1.093^{d} ±0.00	1.058^{e} ±0.00	1.104^{b} ±0.00	691.05^{g} ±0.00	5509.22^{d} ±0.00
Alphonso	16.80^{de} ±0.80	44.00^{b} ±0.26	0.210^{g} ±0.01	0.242^{e} ±0.00	1.077^{f} ±0.00	1.109^{b} ±0.00	1.052^{f} ±0.00	1.105^{b} ±0.00	709.05^{f} ±0.00	6618.00^{c} ±0.00
Shendi	16.00^{e} ±1.00	23.50^{c} ±0.52	0.223^{f} ±0.00	0.242^{e} ±0.00	1.085^{e} ±0.01	1.116^{a} ±0.00	1.073^{d} ±0.00	1.113^{a} ±0.00	1466.09^{e} ±0.00	6945.32^{b} ±0.00
Neelum	16.48^{e} ±0.21	18.00^{d} ±1.00	0.252^{d} ±0.00	0.372^{a} ±0.00	1.065^{h} ±0.00	1.105^{c} ±0.00	1.058^{e} ±0.00	1.085^{c} ±0.00	446.30^{h} ±0.00	7803.13^{a} ±0.00

*Values are presented as mean ± SD. Any two-mean value(s) bearing the same superscript(s) in a column are not significantly different (P≤0.05).

4.3. Interaction Effect: Processing and Cultivar

The combined effect of processing (concentration) and cultivar variation on the physicochemical properties was highly significant ($p \leq 0.05$), as presented in Tables 5 and 6. Vacuum concentration consistently and significantly increased the values of titratable acidity, all sugar fractions, pH, TSS, ascorbic acid, non-enzymatic browning, density, and viscosity across all four cultivars compared to their initial state as fresh pulp. For instance, the TSS of the Neelum cultivar increased from 15.00% to 22.00% after concentration. The magnitude of these increases, however, varied depending on the specific cultivar.

4.4. Rheological Properties

The rheological behavior of the mango pulps and concentrates was effectively described by the Herschel-Bulkley model. The model parameters yield stress (y_0), consistency

coefficient (k), and flow behavior index (n) are presented in Tables 7, 8, and 9.

A significant interaction was found between the mango cultivar and the processing stage on these rheological parameters (Table 7). Overall, vacuum concentration led to a significant increase ($p \leq 0.05$) in the yield stress and flow behavior index, while the consistency coefficient decreased significantly ($p \leq 0.05$) across all cultivars (Table 9).

At 30 ℃, the concentrates from different cultivars exhibited distinct flow behaviors (Table 8). The Kitchener and Neelum concentrates demonstrated thixotropic behavior with a yield stress ($n > 1$). The Alphonso concentrate showed a mixed behavior of pseudoplastic and thixotropic characteristics. In contrast, the Shendi concentrate displayed typical pseudoplastic (shear-thinning) behavior with a yield stress ($n < 1$).

5. Discussion

5.1. Modifications in Physicochemical Properties Following Vacuum Concentration

The vacuum concentration process induced substantial changes in the physicochemical properties of the four mango pulp varieties. Analysis revealed statistically significant increases ($p \leq 0.05$) in total soluble solids (TSS), total sugars, reducing sugars, non-reducing sugars, ascorbic acid content, and apparent viscosity following processing (Tables 1, 2, 5, 6). This phenomenon can be directly attributed to the fundamental principle of concentration through water removal, which effectively increases the concentration of soluble constituents per unit volume. These findings are consistent with previous research on fruit concentration, particularly the work of [31] on Sudanese mango varieties.

A noteworthy observation was the significant increase in titratable acidity post-concentration. This aligns with findings by in [32] in grape juice concentrates, who reported acidity ranges of 0.8-2.4 g/100g for white and 0.8-3.4 g/100g for red juice concentrates. The concentration of organic acids through water evaporation provides a logical explanation for this increase. However, this contrasts with results reported by [33] for apricot and peach concentrates, suggesting fruit-specific responses to concentration processes.

The significant enhancement in ascorbic acid content, despite thermal processing, underscores the advantage of vacuum concentration. The reduced processing temperature and limited oxygen exposure under vacuum conditions likely minimized degradation, allowing the concentrating effect to predominate, thereby improving the nutritional profile of the final product.

Table 7. Effect of processing and Sudanese mango varieties on their Rheological properties on (Herschel-Bulkley Model)*

Mango cultivar	Yield stress(y_0) (Pa)		Consistency coefficient (k) (Pa.s^n)		Flow behavior index (n)	
	Processing stage					
	Before	After	Before	After	Before	After
Kitchener	$12.25^f \pm 0.03$	$131.70^b \pm 0.09$	$0.09176^e \pm 0.00$	$0.0078^h \pm 0.00$	$0.8561^f \pm 0.00$	$1.355^a \pm 0.01$
Alphonso	$11.72^g \pm 0.01$	$53.32^d \pm 0.06$	$1.292^a \pm 0.01$	$0.04563^f \pm 0.00$	$0.5069^h \pm 0.00$	$1.279^b \pm 0.01$
Shendi	$12.91^e \pm 0.03$	$62.51^c \pm 0.07$	$0.7186^b \pm 0.00$	$0.6756^c \pm 0.00$	$0.6219^g \pm 0.00$	$0.8836^e \pm 0.00$
Neelun	$11.32^h \pm 0.01$	$140.40^a \pm 0.11$	$0.1717^d \pm 0.00$	$0.02289^g \pm 0.00$	$0.9107^d \pm 0.00$	$1.203^c \pm 0.01$
P-value	0.0		0.0		0.0	

*Values are presented as mean ± SD. Any two-mean value(s) bearing the same superscript(s) in a column are not significantly different ($P \leq 0.05$).

Table 8. Effect of processing and Sudanese mango varieties on their Rheological properties on (Herschel-Bulkley Model)*

Mango cultivars	Yield stress (y_0) (Pa)	Consistency coefficient (k) (Pa.s^n)	Flow behavior index (n)
Kitchener	$71.97^b \pm 0.13$	$0.04978^d \pm 0.00$	$1.106^a \pm 0.02$
Alphonso	$32.52^d \pm 0.10$	$0.6688^b \pm 0.03$	$0.8929^c \pm 0.01$
Shendi	$37.71^c \pm 0.08$	$0.6971^a \pm 0.05$	$0.7527^d \pm 0.0$
Neelun	$75.86^a \pm 0.15$	$0.0973^c \pm 0.01$	$1.057^b \pm 0.02$
P-value	0.0	0.0	0.0

*Values are presented as mean ± SD. Any two-mean value(s) bearing the same superscript(s) in a column are not significantly different ($P \leq 0.05$).
(Pa): Pascal unit, Pa.sn: Pascal. Second

Table 9. Effect of processing on their Rheological properties on (HB Model)*

Processing	Before concentration	After concentration	P-value
Yield stress y_0 (Pa)	$12.05^b \pm 0.08$	$96.98^a \pm 0.13$	0.0
Consistency coefficient (k) (Pa.s)	$0.569^a \pm 0.00$	$0.188^b \pm 0.00$	0.0
Flow behavior index (n)	$0.724^b \pm 0.01$	$1.180^a \pm 0.02$	0.0

*Values are presented as mean ± SD. Any two-mean value(s) bearing the same superscript(s) in a column are not significantly different ($P \leq 0.05$).
(Pa): Pascal unit, Pa.sn: Pascal. Second

5.2. Rheological Behavior and Model Fitting

The rheological characterization demonstrated that the Herschel-Bulkley (HB) model effectively described the flow behavior of both fresh pulps and concentrates at 30 ℃. The model parameters revealed significant alterations in rheological properties due to processing. Specifically, vacuum concentration resulted in a universal increase in yield stress and flow behavior index across all cultivars, while the consistency coefficient decreased significantly (Table 9).

Distinct rheological behaviors were observed among cultivars. The Shendi concentrate exhibited pseudoplastic behavior with yield stress, consistent with findings by [34] for mango pulp and [35] for ginger paste. In contrast, Kitchener and Neelum concentrates displayed thixotropic behavior with yield stress, while Alphonso showed mixed pseudoplastic and thixotropic characteristics. These variations can be attributed to differences in fibrous material content and composition among cultivars, supporting the observations of [36] regarding the influence of discontinuous phase substances on rheological behavior.

The increase in yield stress values following concentration aligns with the fundamental relationship between solid content and structural strength in food dispersions. As [37] noted, yield stress depends on particle size distribution and interactions, which are inevitably altered by concentration processes.

5.3. Inter-cultivar Variability and Industrial Implications

The significant differences in both physicochemical and rheological properties among the four cultivars (Tables 3, 4, 7, 8) highlight the crucial role of genetic factors in determining processing behavior and final product quality. This cultivar-specific variability has substantial implications for industrial applications.

The distinct rheological profiles observed necessitate customized approaches to process design and equipment selection. For instance, the thixotropic behavior of Kitchener and Neelum concentrates requires consideration of time-dependent viscosity changes in pumping system design, while the pseudoplastic nature of Shendi concentrate demands different handling parameters.

These findings provide valuable insights for the Sudanese mango processing industry, enabling strategic cultivar selection based on desired product characteristics and processing requirements. The research establishes a scientific basis for optimizing concentration processes specific to local mango varieties, potentially enhancing product quality and processing efficiency.

6. Conclusions

The study aimed to assess how vacuum concentration impacts the physicochemical and rheological properties of mango pulp and its concentrates. Physicochemical and rheological traits of four mango cultivars (Kitchener, Alphonso, Shendi, and Neelum) were analyzed before-after processing. The examination revealed increased levels of total soluble solids (TSS), viscosity, and total sugars after processing. Variations in rheological parameters such as yield stress, consistency coefficient, and behavior index were noted across the mango varieties. Kitchener and Neelum concentrates demonstrated thixotropic behavior with yield stress, Alphonso showed a combination of pseudoplastic and thixotropic characteristics, while Shendi exhibited pseudoplastic behavior with yield stress. Physical treatments are recommended for Kitchener and Neelum mango concentrates to reduce fiber content, potentially enhancing heat transfer and pumpability.

CRediT Authorship Contributions Statement

Fatima M. Mohamed: Conceptualization, writing-original draft, supervision, methodology, data curation and editing. **Najlaa Siddig Nasir:** Conceptualization, writing-original draft. **Waheeba Elfaki**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Ammar AL-Farga:** Methodology, writing-Review, and editing **Fatima Fadul Ali:** Conceptualization, Methodology, writing-Review, and editing. **Islam Ragab**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

ACKNOWLEDGEMENTS

The Researchers would like to thank the Deanship of Graduate Studies and Scientific Research at Qassim University for financial support (QU-APC 2025).

Data Availability

All data is included within the search.

REFERENCES

[1] Reis, R.C., et al., *Physical, chemical and sensory attributes of fruits of ten mango varieties grown under organic production system*. Revista Caatinga, 2021. 34: p. 452-459.

[2] Eni, A.O., I.A. Oluwawemitan, and O.U. Solomon, *Microbial quality of fruits and vegetables sold in Sango Ota, Nigeria.*

African Journal of Food Science, 2010. 4(5): p. 291-296.

[3] Ara, R., et al., *Nutritional evaluation of different mango varieties available in Bangladesh.* International Food Research Journal, 2014. 21(6): p. 2169-2174.

[4] Ugese, F., P. Iyango, and T. Swem, *Mango (mangifera indica L.) fruit production and production constraints in gboko local government area of Benue state.* Publication of Nasarawa State University, Keffi, 2012. 8(1): p. 164-174.

[5] Zhang, W., G. Zhu, and G. Zhu, *The imitation and creation of a mango flavor.* Food Science and Technology, 2022. 42: p. e34622.

[6] Rodr ́guez Pleguezuelo, C., et al., *Physico-chemical quality parameters of mango (Mangifera indica L.) fruits grown in a Mediterranean subtropical climate (SE Spain).* Journal of Agricultural Science and Technology, 2012. 14(2): p. 365-374.

[7] Kantanet, N. and P. Chompoorat. *Impact of Storage Temperature on Physiological Changes and Shelf Life of Mango CV. Mahachanok. in 6th International Conference of Food, Agriculture, and Natural Resource (IC-FANRES 2021).* 2022. Atlantis Press.

[8] Monira, S., et al., *Post-harvest factors affecting quality and shelf life of mango cv. Amropali.* Research in Agriculture Livestock and Fisheries, 2016. 3(2): p. 279-286.

[9] Javanmard, M. and J. Endan, *A survey on rheological properties of fruit jams.* International Journal of Chemical Engineering and Applications, 2010. 1(1): p. 31.

[10] Rahman, M., et al., *Postharvest loss assessment of mango in the existing value chain of Bangladesh.* J. Bangladesh Hortic, 2017. 3: p. 12-22.

[11] Phaokuntha, S., P.B. Poonlarp, and I. Pongsirikul. *RHEOLOGICAL PROPERTIES OF MANGO PUREE AND PROCESS DEVELOPMENT OF MANGO SHEET.* 2014. International Society for Horticultural Science (ISHS), Leuven, Belgium.

[12] FAO, *Handbook of Fruit and Vegetable Processing.* 2009: Viale delle Terme di Caracalla, 00153 Rome, Italy.

[13] Zuritz, C., et al., *Density, viscosity and coefficient of thermal expansion of clear grape juice at different soluble solid concentrations and temperatures.* Journal of Food Engineering, 2005. 71(2): p. 143-149.

[14] Salama, O.E., et al., *RHEOLOGICAL PROPERTIES OF DATE JUICE CONCENTRATE (DIBS) DURING EVAPORATION PROCESS.* Misr Journal of Agricultural Engineering, 2017. 34(1): p. 317-330.

[15] Diamante, L. and M. Umemoto, *Rheological properties of fruits and vegetables: a review.* International Journal of Food Properties, 2015. 18(6): p. 1191-1210.

[16] Ahmed, W.E., et al., *Effect of sprouting whole wheat grain on the sensory quality, physicochemical properties, and antioxidant activity of cupcakes.* Applied Food Research, 2024. 4(1): p. 100412.

[17] Ahmed, W.E., et al., *Physicochemical, Antioxidant, and Sensorial Properties of Xylopia aethiopica (Komba) Fruit on Mish Quality.* Current Research in Nutrition and Food Science Journal, 2025. 13 (Special Issue Phytonutrients July 2025): p. 219-228.

[18] Abbas, K., et al., *Suitability of viscosity measurement methods for liquid food variety and applicability in food industry-A review.* Journal of Food Agriculture and Environment, 2010. 8(3-4): p. 100-107.

[19] Concei ção, M.C., et al., *Effect of sucrose and pectin addition on physical, chemical, thermal and rheological properties of frozen/thawed pineapple pulps.* Korea-Australia rheology journal, 2012. 24: p. 229-239.

[20] Ibarz, A., et al., *Rheological behaviour of kiwi fruit juice concentrates.* Journal of texture studies, 1995. 26(2): p. 137-145.

[21] Salehi, F., *Physicochemical characteristics and rheological behaviour of some fruit juices and their concentrates.* Journal of Food Measurement and Characterization, 2020. 14(5): p. 2472-2488.

[22] Augusto, P.E., M. Cristianini, and A. Ibarz, *Effect of temperature on dynamic and steady-state shear rheological properties of siriguela (Spondias purpurea L.) pulp.* Journal of Food Engineering, 2012. 108(2): p. 283-289.

[23] El-Mansy, H., et al., *Rheological properties of mango and papaya nectar blends.* Ann. of Agric. Sc., Moshtohor, 2005. 43(2): p. 665-686.

[24] Quek, M.C., N.L. Chin, and Y.A. Yusof, *Modelling of rheological behaviour of soursop juice concentrates using shear rate–temperature–concentration superposition.* Journal of Food Engineering, 2013. 118(4): p. 380-386.

[25] Vishal, B., et al., *Quality evaluation of enzyme liquefied papaya juice concentrate (PJC) stored at various temperatures.* Journal of Food and Nutrition Sciences, 2015. 9(2): p. 90-97.

[26] Mandha, J., et al., *Characterization of fruit juices and effect of pasteurization and storage conditions on their microbial, physicochemical, and nutritional quality.* Food Bioscience, 2023. 51: p. 102335.

[27] A.O.A.C., *Official Methods of Analysis.* Vol. 18th. 2005: Gaithersburg, Mary Land 20877-2417, USA.

[28] Ranganna, S., *Manual of analysis of fruit and vegetable products.* Tata Mc. Graw Hill Publishing Company Ltd., New Delhi., 1977: p. 9-82.

[29] Askar, A. and H. Treptow, *Quality assurance in tropical fruit processing.* 2013: Springer Science & Business Media.

[30] Aflakpui, G.K., *Some uses/abuses of statistics in crop experimentation.* Tropical Science, 1995. 35(4): p. 347-353.

[31] Nour, A.A., K.S. Khalid, and G.A. Osman, *Suitability of some Sudanese mango varieties for jam making.* Am. J. Ind. Res, 2011. 2: p. 17-23.

[32] Haight, K.G. and B.H. GuMP, *Red and white grape juice concentrate component ranges.* Journal of Food Composition and Analysis, 1995. 8(1): p. 71-77.

[33] El hadad, A.S., et al., *Influence of some Additives on the properties of concentrated apricot and peach juices during freeze storage., in International Conference on Ecological, Environmental and Biological Science.* 2013: Hongkong (china).

[34] Bhattacharya, S., *Yield stress and time-dependent rheological properties of mango pulp.* Journal of food science, 1999. 64(6): p. 1029-1033.

[35] Ahmed, J., *Effect of temperature on rheological characteristics*

of ginger paste. Emirates Journal of Agricultural Sciences, 2004. 16(1): p. 43-49.

[36] Goula, A.M. and K.G. Adamopoulos, *Rheological models of kiwifruit juice for processing applications.* Journal of Food Processing and Technology, 2011. 2(1): p. 106 ref. 45.

[37] Servais, C., R. Jones, and I. Roberts, *The influence of particle size distribution on the processing of food.* Journal of food engineering, 2002. 51(3): p. 201-208.