ISSN: 2347-467X, Vol. 08, No. (2) 2020, Pg. 496-503

Current Research in Nutrition and Food Science

www.foodandnutritionjournal.org

Rheological, Tribological, and Sensory Analysis of Coconut-Oil-Modified Coconut Milk Kefir

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Abstract

Kefir made of coconut milk (CM) was developed as an alternative healthy beverage for elderly people. Coconut oil (CO; 0–15%) was added to modify the texture and mouthfeel of the final product. This study aimed to determine the viscosity, flow behavior, frictional properties, textural attributes, and oral processing time of the fermented CM beverage. We have defined the optimum level of CO that gives stability to the product and triggers specific sensory perceptions associated with viscosity and body characteristics. The sensation of roughness, a surface-related property, was also observed and dominated the later stage of oral processing. The current study describes the unique sensations that characterize the CO-modified CM kefir that targets elderly consumers. In addition to its nutritional benefits, CO can be added to enhance the perception of texture and mouthfeel when drinking the fermented beverage.

Article History

Received: 30 December 2019
Accepted: 09 June 2020

Keywords

Coconut Milk;
Coconut Oil;
Kefir;
Mouthfeel;
Rheology;
Sensory;
Texture;
Tribology.

Introduction

Elderly people are an emerging population with specific physiological and nutritional requirements. Eating and swallowing are often problematic for elderly people, primarily associated with oral surface coating and lubrication and dynamic textural perception during oral food processing.[1] Not only high-value energy sources and a potential source of essential fatty acids, fats and oils provide lubrication to food products by softening their structure.[2] The use of fats to modify the texture of oil-in-water emulsions is an approach that can be used to address the

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Doi: http://dx.doi.org/10.12944/CRNFSJ.8.2.15

problem of declining taste and perceptions for the elderly.[13]

In the development of texture-modified (TM) foods for aging people, in-mouth processing and perceptions can be precisely determined by food rheology and oral tribology.[4] The latter encompasses the study of both the rheological properties of lubricating fluids and the surface properties of the interacting substrates in relative motion.[5] Quantitative data can be related to sensory descriptive terms, providing insight into sensory perceptions of food products. In characterizing complex oral food processing, however, most studies use several factors, such as ingredients and/or processing conditions, and determine their effects on multiple domains, thus making it difficult to associate a single factor's effect on subtle changes in textural data, which is, by its nature, multimodal. Sensory perception, especially those related to fat content, do not necessarily correlate with the sample viscosity, but rather its lubrication properties. For example, fat content was used as a single determining factor affecting the mouthfeel attributes of fluid foods and beverages and the friction factor was found to relate with sensory perceptions of creaminess.[6] In a dairy-based yoghurt, the rheological and tribological properties as affected by fat content and hydrocolloids were determined, and later, a numerical predictive model of sensory scores was proposed.[7]

One problem the current study aimed to overcome was the fact that the interpretation of a texture using multiple factors can fail to capture the contribution of single underlying variables in a dynamic oral processing event to elicit sensory perceptions linked to certain stimuli. Fat, in particular, being a sensation and/or a new taste, the mode or mechanism used in sensory perception is still inconclusive. However, as has been evidenced in many studies, humans are able to detect a wide spectrum of free fatty acids[8]; the fats used in TM foods may therefore have potential applications in enhancing perception and preference of elderly people. For this reason, the current study focused on oil content as a single factor affecting texture modification of a plant-based liquid food, coconut milk (CM) kefir. Coconut oil (CO) contains a majority of medium-chain triglycerides and serves as a stimulus of fat-related sensory perception. Kefir, which has been a rising trend in the healthy beverage segment, was used as a model liquid system. Kefir is a fermented milk beverage prepared by fermenting milk with kefir grains or a starter comprising a symbiotic community of bacteria and yeast. Compared to regular yoghurt, kefir offers greater health benefits due to its higher total microbial count and strain diversity. In this context, this study aimed to characterize the texture and mouthfeel of CO-modified CM kefir using rheological and tribological techniques and determine the effect of CO content on sensory perceptions by elderly subjects. This information on the texture and mouthfeel of oil-added beverages will be beneficial in the design of personalized foods addressing the specific physiological and nutritional issues of elderly people.

Materials and Methods

Preparation of CO-Modified CM Kefir

An instant kefir starter (Cutting Edge Cultures; Wakefield, RI) was added to CM (Chaokoh, Ampol Food Processing Ltd.; Nakhonpathom, Thailand) at a ratio of 5:1, mixed, and left to ferment at room temperature for 24 hours. A mixture of xanthan gum (Judee's Gluten Free, Gluten Free You and Me; Plain City, OH) and guar gum (Modernist Pantry, LLC; Eliot, ME) was prepared and added to the fermented CM. The mixture was added with 0, 5, 10, 15, and 20% CO (Virgin coconut oil organic, Earth Born Co. Ltd.; Vadhana, Thailand) and homogenized at 21,500 rotations per minutes (RPM) for 10 minutes (Ultra-Turrax T25, IKA; Staunfen, Germany) before being refrigerated at 3–5^{o}C.

Preparation of Artificial Saliva

Artificial saliva was prepared according to the method for studying tribology in yogurts.[9] All the reagents were of analytical grade. The components were sodium chloride (Merck, 0.117 g L^{-1}), potassium chloride (Merck, 0.149 g L^{-1}), sodium bicarbonate (Merck, 2.100 g L^{-1}), mucin from type II porcine stomachs (Sigma, M2378; 1.000 g L^{-1}), α-amylase from type VI-B porcine pancreas (Sigma, A3176; $\geq$ 5 units/mg solid, 0.800 g L^{-1}), and LC-MS grade double-distilled water. For the *in vitro* digestion, the saliva-to-sample ratio was 1:4.

Rheological Analysis

The viscosity and flow behavior of the samples was determined using a modular compact rheometer

(Model MCR 302; Anton Paar, Austria) with parallel-plate geometry, a 50-mm diameter for the upper plate, and a gap width of 1 mm at 25°C. The shear-rate-controlled test was carried out with 100 measuring points using ascending logarithmic steps. The total measuring time was t = 200 seconds; this corresponds to 2 seconds for each measuring point. The viscosity and shear stress were recorded between 0 and 1000 s^{-1}.

Tribological Analysis

The frictional properties of the samples were analyzed using a tribological measuring cell (T-PTD 200) mounted to a modular compact rheometer (Model MCR 302; Anton Paar, Austria) with a ball-on-three-pin measurement geometry. The geometry consisted of a sample holder for three cylindrical 6-mm PDMS pins placed on a Peltier temperature control system, whereas the measuring system shaft holding a 0.5" soda-lime glass ball was connected to a motor. The normal force was controlled by the rheometer at 1 N, whereas the system temperature was set to remain constant at 37°C (a typical human body temperature). For each analysis, the measuring method was programmed to run in two consecutive intervals. First, the system was allowed to relax with the freshly applied load. Second, the speed was increased from 10-6 RPM to 2000 RPM. The friction force that corresponded to the sliding/rotational speed of the tribological system (the Stribeck curves) was recorded between 0.01 and 1,000.00 mm/s and analyzed by RHEOPLUS/32 software (Version 3.62). The effect of the artificial saliva on the frictional behavior was also studied.

Sensory Analysis

The sensory evaluation was conducted by six trained, healthy panelists (five females and one male) aged 60–70 years, using quantitative descriptive analysis (QDA®). All the panelists gave their informed consent to participate in tests involving non-standard foods.[10] They were chosen for their ability to distinguish four basic tastes and textures.[11] The panelists generated the textural attributes (Table 1) associated with commercial spoonable yoghurts during a training session (12 h); these attributes were later used to evaluate the texture of the in-house spoonable samples. For each textural attribute, commercial yoghurts (both set and drinking types) with low and high intensities were provided as anchor points during the training sessions. The panelists evaluated the in-house samples using a linear scale with increasing scores from 0 to 15 and with anchors marked at 7.5 cm from either end. Four samples with different coconut oil concentrations (0, 5, 10, and 15%) were served in a randomized order to the subjects. Each sample test and each of the sensory evaluations were conducted in triplicate, divided over three 30-minute sessions spaced 15 minutes apart. Equal amounts of each spoonable kefir were prepared in 90-mL glass containers labelled with randomly selected three-digit codes and equilibrated at room temperature for at least 15 minutes before consumption. The samples were served to the panelists with spoons and with water and unsalted crackers for palate cleansing.

Table 1: Definitions of the Textural Attributes

Attributes	Definitions
Consistency	The perceived homogeneousness in the mouth
Viscosity	The friction against flow detected by the moving tongue
Smoothness	The perceived smoothness of the sample squeezed between the palate and tongue
Roughness	The perceived inconsistency caused by soft lumps present in the sample
Body	The sensation of mass in the mouth

Determination of Oral Processing Time

The sensory panelists were instructed to suck the whole volume of the liquid sample (5 mL) into their mouth at once. They were then asked to press the stopwatch, start drinking, then press the stopwatch again when they had finished drinking and orally processing the sample to indicate the drinking end point. The end point was defined as the self-reported "total drinking time," which included multiple swallows and the oral clearance time needed to remove residues or oral coatings from the tongue surface.[12] The panelists were asked to rinse their mouth with water during the breaks between samples.

Statistical Analysis

All data were analyzed using statistical software XLSTAT (verson 2020.2.3, Addinsoft; New York, NY, USA). A one-way analysis of variance (ANOVA) test with pairwise comparisons post-hoc was performed on each data set to look for significant main effects. Significance was set at $P < 0.05$.

Results and Discussion

Rheological and Tribological Behaviors of Co-Modified Cm Kefir

The current study used instant coconut milk (CM), which is a natural oil-in-water emulsion that has already undergone homogenization and ultra-high-temperature processing. In general, processed CM contains five times more fat and two times less protein than full-fat milk.[13] The protein content and quality of CM is not sufficient to stabilize the dispersed fat globules. Therefore, to improve colloidal stability, a mixture of hydrocolloid was added to the CM before homogenization. Homogenized CM containing 2% protein and 18% fat was highly flocculated in the absence of added stabilizers.[14] The current study found that the optimum level of hydrocolloid mixture needed to provide a desirable level of viscosity and stability to the fermented CM is 0.4%. The stabilized CM was then added to the CO; homogenization followed. The oil-added CM was a shear-thinning fluid. A separation in viscosity at its flow point was observed between 5% and 10% of CO treatment; the latter provided more rigidity to the CO-modified CM kefir (Figure 1).

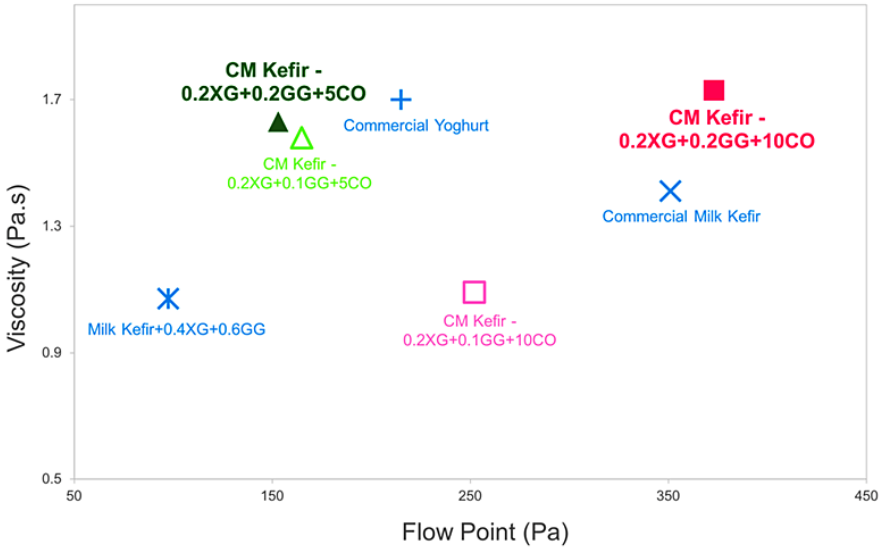

Fig.1: Effect of Coconut Oil (CO) Content and Hydrocolloids (XG=Xanthan Gum; GG=Guar Gum) on CO-Modified CM Kefir Stability Characterized as Viscosity (Pa.s) as a Function of Flow Point (Pa) in Comparison with Commercial Milk- and Dairy-Based Yoghurts

CO is predominantly 92% saturated fat, containing 64% medium-chain fatty acids (MCFAs).[15] Nutritionally, this unique type of saturated fat is reported to boost metabolism, reverse insulin resistance, and improve cognitive function.[16] The MCFAs in coconut oil are easy to digest and can be absorbed quickly; they are thus recommended for older people. Perceptions of fat-related attributes differ from person to person and can be explained by physiological mechanisms, such as tactile modality, fat properties, product rheology, and in-mouth processing.[17] In developing TM kefir products, therefore, a relationship between instrumental and sensory textures is useful for describing kefir's texture and mouthfeel sensations based on the unique melting temperature of CO and its interaction with saliva.[18] In tribological analysis, the Stribeck curve was used to assess the mouthfeel attributes of the products by characterizing the changes in the friction factors between the interacting surfaces as a function of the sliding speed. To simulate human oral processing environments, artificial saliva was also introduced into our tribological system, and the temperature of the system was set at 37°C. We found that changes in the frictional factors fell into three distinct transitions. The transitions of the friction values were observed at sliding speeds of 3.9, 32.0, and 1,628*10-2 mm/s, thus dividing the Stribeck curve into four separate zones. The tribology pattern and the three transitions (T1–3) in Figure 2 and the corresponding mean values can be seen in Table 2. Translating tribological data into an in-mouth oil-in-water emulsion destabilization, the observed pattern suggested that oil-added CM liquids undergo destabilization where coagulated fat droplets in the liquid are absorbed into the interacting surfaces. As the sliding speed increased, shearing caused the trapped liquid to dissipate, causing the two surfaces to come into closer in contact, and thus the rise in friction value was observed. As part of the shearing progress, fat droplets flocculated by interacting with salivary proteins on the surface and in the bulk solution and formed a lubricious layer that decreased the friction values after the final transition.

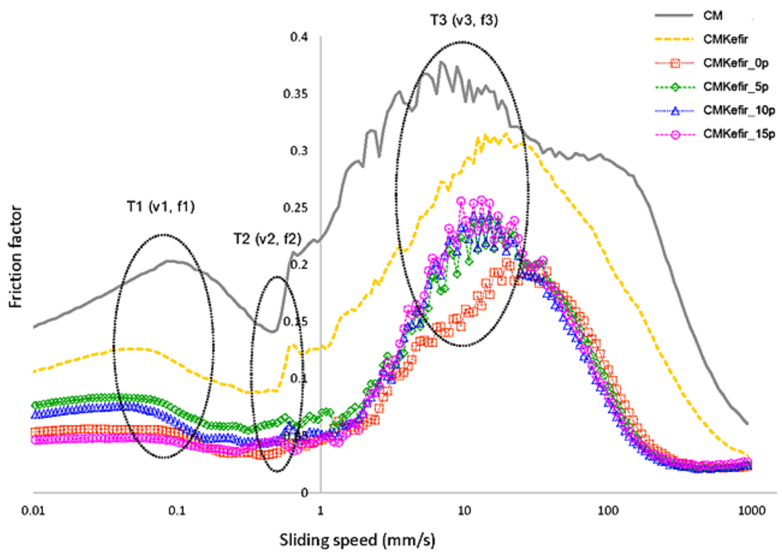

Fig. 2: Tribological Data for Coconut Milk (CM) and CO-Modified CM Kefir with Different Levels of Added Coconut Oil (CO) Content

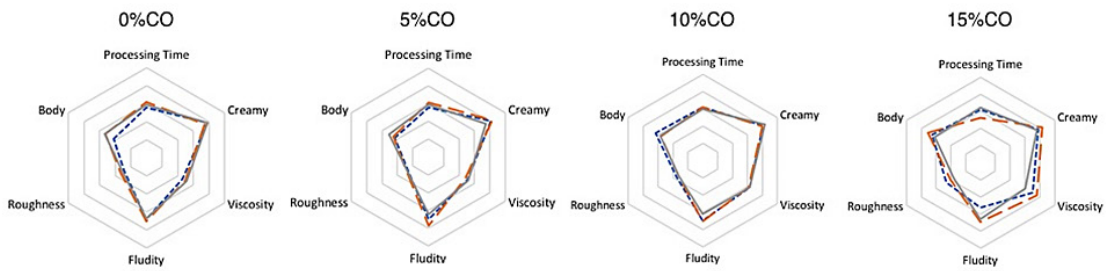

Fig. 3: Mean Sensory Scores for Five Attributes and Oral Processing Time Determined for Fermented CM Drink in Three Separate Sessions (Different Line Patterns)

Table 2: Mean Tribological Behaviors of Coconut Milk (CM) and CM Kefir with Different Levels of Added Coconut Oil (CO) Content

Sample	CO (%)	Tribological Behaviors*					
		v1	f1	v2	f2	v3	f3
CM	-	9.61^{f}	0.19d	4.50^{a}	0.15^{d}	733^{a}	0.38^{d}
CMKefir**	-	6.07^{e}	0.13c	38.10^{ab}	0.08^{c}	2000^{c}	0.32^{c}
CMKefir_0p	0	2.50^{a}	0.06^{a}	39.40^{ab}	0.03^{a}	1960^{c}	0.19^{a}
CMKefir_5p	5	4.99^{d}	0.09^{b}	31.30^{ab}	0.06^{b}	1610^{b}	0.24^{b}
CMKefir_10p	10	4.37^{c}	0.06^{b}	31.70^{ab}	0.04^{a}	1500^{b}	0.24^{b}
CMKefir_15p	15	3.60^{b}	0.05^{b}	25.70^{b}	0.03^{a}	1440^{b}	0.24^{b}

*Tribological behaviors at selected transitions: v = sliding speed (10^{-2} mm/s), f = friction factor. **Fermented CM without hydrocolloids.
$^{a\text{-}f}$Means within the same column having the same superscript or without a superscript are not significantly different ($p > 0.05$; $n = 3$).

Sensory Perception of CO-Modified CM Kefir and its Relationship with Tribology

The QDA was conducted by six trained panelists aged between 60–70 years old to determine their ability to discriminate taste stimuli. Figure 3 shows the mean sensory attribute score of CM Kefir for each of the four levels of added CO, and Table 3 represents the mean values and their significance. Based on the subject's sensitivity, i.e., their ability to discriminate differences, we found that the key sensory attributes for CO-modified CM kefir were viscosity, roughness, and body. A separation in each subject's perception of these key attributes was observed between 5% and 10% CO, which seems to align with the oral processing times, which averaged 9 minutes. In addition, at a higher 15% concentration of CO, a discrepancy in the sensory scores among the three QDA sessions was observed, suggesting that the subjects had reached the limit of their ability to discriminate CO content (Figure 3).

Table 3: Mean Sensory Attribute Score and Oral Processing Time of Coconut Milk (CM) Kefir with Different Levels of Added Coconut Oil (CO) Content

Sample	CO (%)	Sensory Attributes					Oral Processing Time (sec)
		Creamy	Viscosity	Fluidity	Roughness	Body	
CMKefir_0p	0%	11.54	7.36^{a}	10.25	4.65^{a}	7.41^{a}	8.8
CMKefir_5p	5%	11.93	7.54^{a}	10.57	4.20^{a}	7.00^{a}	8.8
CMKefir_10p	10%	12.19	9.34^{b}	10.11	5.11^{ab}	8.83^{b}	9.2
CMKefir_15p	15%	11.88	10.36^{b}	9.37	6.13^{b}	9.86^{b}	8.9

$^{a\text{-}f}$Means within the same column having the same superscript or without a superscript are not significantly different ($p > 0.05$; $n = 6$).

Initially, the panel was trained with both dairy- and plant-based beverages with different levels of fat. The absence of significance in terms of creaminess and fluidity observed afterward in the QDA sessions was possibly due to the nature of CO and CM. The fact that the melting temperature of CO is lower than body temperature (around 37°C)[19] causes it to melt quickly on the tongue and create a drier mouthfeel. In addition, since CM has a lower protein content, its interaction with saliva is different from that of its dairy-based counterparts. Future study needs to further investigate the sensitivity of elderly subjects in the perception of fats as related to their melting temperature and protein-saliva interaction.

The results of this study suggest that the elderly perceive low-viscosity liquid products with oil contents ranging from 0–5% as being low-fat, whereas they perceive those with oil contents above 10% as being high-fat. They also tended to take a longer time to process the higher-fat levels within their mouths. Beyond 10% CO, however, their evaluation for each attribute started to deviate from the mean value across sessions (Figure 3). This deviation might suggest the subjects' sensitivity loss at this CO level. Taste loss in elderly people associated with their elevated taste thresholds or sensitivities to chemosensory stimuli has been reported for the five basic tastes but has never been reported for fat content.[20] In relating sensory to tribological analysis, that data in our study suggested the role of fat in enhancing sensory perceptions of texture and mouthfeel for the elderly. The lowest score out of all the sensory descriptors was observed for the 0% CO sample, which is in line with its significant drop and delay in friction response at around transition point three. This relationship may be useful in enhancing the perception and pleasantness of the beverage or controlling its intake. For CM kefir, 10% is probably the highest level of added CO to achieve specific sensation.

Conclusion

We have characterized the rheological and tribological properties of CM kefir and defined its key sensory attributes. CO can be used to improve the texture and mouthfeel of this plant-based fermented beverage. The optimum level of CO at 10% gave stability to the product and triggered specific sensory perceptions associated with viscosity and body characteristics. The sensation of the surface-related property of roughness was observed in the later stage of oral processing. Specific to low-viscosity fermented drinks, CO can help enhance sensory perceptions in the elderly.

Acknowledgements

Authors are grateful to the Institute of Food Research and Product Development, Kasetsart University, Thailand for providing facilities to carrying out the current study.

Funding

This research project was finacially supported by the Agricultural Research Development Agency (Public Organisation), Thailand.

Conflict of Interest

The authors declare no conflict of interest.

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