TRIBIOLOGY IS A TOOL FOR SENSORY EVALUATION OF DAIRY FOODS

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Abstract: *Food oral processing is a study of mastication that involves food-saliva interaction. Tribology is a modern oral processing tool that is an important technology for evaluating the oral sensations of various food items such as smoothness and creaminess. Instrumental approaches have improved sensorial attributes like texture by stimulating the oral environment for the past years. The paper covered state of the art on instrumentation, working principles, the efficiency of the tribometer and its application in dairy foods i.e. milk, cream, cheese, yogurt , curd , milk gel etc..*

Keyword: Oral processing, Textural analysis, Tribology principle, Tribometer instrumentation, Dairy applications

1. Introduction:

Tribology is a method of analysing the oral processing, texture and taste of food. Tribology is the study of the interaction of two surfaces that result in friction or shear due to continuous motion (Chen & Stokes, 2012). It derives from the Greek word "tribos," which means "sliding or rubbing." Thin layer rheology is another name for it. The friction coefficient is define as the ratio of friction force to average load of any dairy food. Tribology in the food products describes the sensory properties of food such as smoothness, slipperiness, creaminess, and astringency (Sudhakar et al., 2020). Food lubricating qualities are examined using the same method used in mechanical engineering to analyse the frictional properties of lubricants. Food functions are engaged in oral processing as a lubricant during digestion and interacting of two surfaces such that tongue and palate. Food oral lubricity is directly affected by saliva type, roughness, speed, direction and its motion. Tribology has introduced a new concept known as soft tribology, which determines the lubrication behaviour of fluids and soft solids.

Tribology may also identify dairy food adulterant such as melamine. Although several methods for detecting melamine adulterants, such as mass spectrophotometry, gas spectrophotometry and high-pressure liquid chromatography, but they are expensive, time-consuming, and need specialist expertise to operate the equipment. Tribology serves as a simple, inexpensive and quick method of identifying melamine adulterants in milk and milk products (Sethupathy et al., 2020).

The tribometer is a sophisticated device that is used as an innovative oral processing tool (Korres & Dienwiebel, 2010). It has gained popularity in recent decades as an excellent method for detecting oral textural feeling. According to this viewpoint, the current study describes the role of tribology as a novel oral processing method for dairy products sensory evaluation. The study focuses on the state of the art in instrumentation, operating principles, tribometer efficiency and its application in dairy products.

2. Types of tribometers:

Several tribometers were used in the field of dairy and food industry. The differences between these tribometers are due to their application (Shewan et al., 2020).

Table 1: Types of tribometer, basic principle and its advantages in dairy and food application.

Tribometer	Principle	Advantage
Mini-traction machine (MTM)	Spinning disk against rotating ball	Sensitive & Accurate, Mostly used in food and dairy product.
Tribology cell	Two cylindrical rotating against annular disk	Inexpensive
Optical tribometer cell (OTC)	Force against oscillating glass surface	Microstructural changes of sample
Friction tester	Spherical ball rotating against rubber band	Simple and easy to use
Ball-on-3-pins rotating tribometer	elastomer pins and a glass probe	Evaluate emulsions property of yogurt
Pin-on-Disk Tribometer	Independent normal load application and friction force measurement	precise elastic arm for friction load measurement
Hybrid Rheometer	using ring on plate tribo-rheometry	Laser based scattering, Used in dairy product

The Ball-on-plate tribometer measures the different sliding shapes of the food products with the help of modular drives. It has been applied in whey protein model foods (Campbell et al., 2017). The three-ball-disc tribometer operates with a texture analyzer linked with a water bath. This tribometer creates a rough surface before analysing the food product. This tribometer is used to test emulsions, wines, and yoghurt (Morell et al, 2017).

3. Tribometer and its working Principle:

The friction behaviour of lubricants is frequently described as Stribeck curve (Douaire, 2014), which plots the friction coefficient as a function of coating thickness. A Stribeck curve is often separated into three regimes: hydrodynamic regime, boundary regime and the mixed regime, which reflect three very distinct friction situations in the case of oral processing, varying amounts of food between the tongue and palate.

(a) **Hydrodynamic regime:** A hydrodynamic lubrication regime is characterised when two surfaces in relative motion are completely separated by a thin layer of fluid. There is no surface wear in this instance, and surface friction rises due to fluid drag force. (**b) Boundary regime:** When surfaces come into close contact, their asperities or roughness can cause the surfaces to lock up, resulting in significant surface wear and a high friction coefficient. This regime might be intimately connected to human perceptions of astringency and slipperiness. **(c) Mixed regime:** The mixed regime of lubrication exists between the boundary and the hydrodynamic regime. Food entrainment into the tongue-palate contact zone is sufficient in this regime to partially separate the two rubbing surfaces. The friction coefficient achieves a low in this domain, and the friction coefficient increases with greater asperity contact or increased lubricant layer thickness.

The elastic deformation of soft contact pairs influences the thickness of the film in the contact region, which influences lubrication behaviour. In the iso-viscoelastic condition has no effect on fluid viscosity (Esfahanian and Hamrock, 1991). The contact type for oral tongue-upper jaw movement is typically thought to be point contact (Kim et al., 2021). Based on Poiseuille flow and Couette flow, the authors derived a prediction equation for the friction coefficient at full submergence (Vicente et al., 2005).

As food is eaten, the friction, lubrication, wears, and tear of the tongue and palate is the basic principle (Sethupathy et al., 2020).

Friction coefficient (μ) is a common physical metric in food oral tribology (Xu et al., 2020).

The tribometer analyses, the frictional force (F_R) stated (Prakash , 2017) as:

$$F_R = \mu \times F_L \text{ --(1)}$$

Where,

μ= friction coefficient, and

F_L = applied force in newton.

The magnitude of friction resistance is proportional to the size of the applied force. The friction coefficient (μ) is crucial because it quantifies the surface contacts. The value of μ depends on the kind of surface roughness. When a lubricant is applied, the value of μ describes the lubrication state among the two surfaces. As a result, the friction coefficient depends on surface properties such as surface load, moving speed, and lubricant property (Prakash et al., 2013).

$$\textbf{Smoothness } \alpha \ 1/\mu_w \text{ --(2)}$$

$$\textbf{Slipperine } \alpha \ 1/\eta(v/h_s)A + \mu_w \text{ --------------------(3)}$$

$$\textbf{Creaminess } \alpha \textbf{ thick}^{0.54} \textbf{ x smooth}^{0.84} \text{--------(4)}$$

Where,

hs: Fluid thickness,

A: Contact surface area,

The horizontal axis combines three variables, namely, the fluid viscosity (η), the relative speed of surface movement (v), and the surface load (F_L). At the same time, the vertical axis is the friction coefficient. Thus, the grouping of three variables yields a fluid thickness (h_s) that mimics the lubricant layer thickness between two surfaces.

A Stribeck curve illustrates three types of friction regimes: boundary, mixed, and hydrodynamic (Sethupathy et al., 2020).

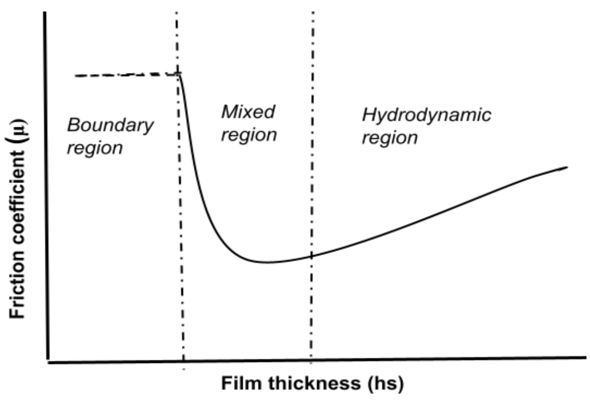

Figure 1: Stribeck curve and different region

Lubrication in the Hydrodynamic regime introduces a low shear strength food coating between the two rubbing surfaces, which sustains the applied strain separating them. Because of surface motion, ingested food reaches the contact zone during the hydrodynamic lubrication process. It generates a large enough quantity of fluid pressure to separate the surfaces (Cassin et al., 2001). The friction caused by hydrodynamic lubrication is determined by the viscosity of the food (Prakash et al., 2013). Consequently, the Stribeck curve provides an appropriate rheological tool for comprehending the physical nature of the sample till the sample fluid generates a high fluid pressure and flow resistance. This is classified as a hydrodynamic regime. Furthermore, the sample nature in mixed and border regimes is not explainable by rheology and necessitates tribological explanation.

4. Applications of tribology in Dairy foods:-

Tribometers such as micro traction machines, OTC, tribo-rheometers, and discovery hybrid rheometers have been utilised in dairy foods to examine the textural qualities of dairy products. Tribometers also detect adulteration of milk and milk products. The development of suitable food models is extremely beneficial in understanding the friction behavior and lubrication mechanism of dairy products.

4.1. Milk and cream:

The tribology of milk analyses in-mouth friction sensations such as particle size, influence of fat, protein and polysaccharide of food products (Miao & Lin, 2019). Researchers in the dairy sector have worked to make low-fat dairy products while maintaining the sensory quality creamy/ oily. The decrease in milk friction with an increase in creamy feeling as fat % increased (Meyer et al., 2011). The tribometer assesses the smoothness and creaminess of food's fat mouth sensory qualities (Campbell et al., 2017). To make milk more appealing, researchers must investigate the sensory qualities of milk as well as its lubricating behaviour during oral movement. Milk perception is influenced by appearance, aroma, texture, and flavour (Phillips et al., 1995). The smooth sensation produced by drinking liquid foods orally has been linked to frictional forces (Kokini et al., 1977). Milk is a low-viscosity fluid; the majority of the friction is caused by the actual contact between the tongue and the upper jaw, and only a very thin single molecule film will remain in the contact gap (Kokini et al., 1987) .

A study of the lubricating and sensory qualities of homogenised milk (fat content 0.1-8%) revealed a linear relationship between perceived mouthfeel and friction (fat level >1%). Friction tests have revealed that the fat content of milk and its coefficient of friction are inversely related at the same speed. The friction curve tends to decrease as fat content increases, and studies with silicone rubber show a substantial influence of increasing fat content (>1%) on the friction coefficient, which is assumed to be due to shear-induced fat agglomeration. (Chojnicka-Paszun et al., 2012). The sensory panel found that higher fat levels rendered the milk emulsion less clear and significantly whiter in colour by assessing the looks of milk with varying fat amounts. This enlightens the development of skim milk and stimulates people to focus on its aesthetic qualities as well as fat reduction in milk (Phillips et al., 1995). Low-fat goods are becoming increasingly popular as a result of the development of a healthy diet. Nonfat milk loses part of its flavour due to the lack of fat. Meyer et al. (2011) employed inulin to increase the taste of skim milk in order to preserve the same taste as low-fat milk.

In a research of milk-added phytosterols, it was discovered that this component can increase emulsion lubrication without altering the flavour of the milk itself (Goh et al., 2021). The effects of saliva and fat on milk and discovered that at high speeds, the friction behaviour of milk may be discriminated (Laguna et al., 2017). Milk with varying fat contents provides a different sensory experience, but this difference is not reflected in rheological properties. Pasteurization is a typical processing procedure for milk, and different pasteurisation processes may create varying impacts on the texture of milk, for example, ultra-pasteurization can cause taste changes in milk (Puri et al., 2016).

That pasteurization had a minimal influence on lubricating behaviour when compared to storage duration, which was owing to the three-dimensional structure created by the interaction of whey protein and casein micelles (Li et al., 2018). Milk-flavored drinks are more popular among young people than pure milk because of their different tastes and some health qualities (Yanes et al., 2018). The percentage of whey protein in emulsions can enhance the lubrication and viscosity of chocolate milk, and a link between the friction coefficient and sensory qualities (powdery feeling, astringency) was discovered (Zhu et al., 2020).

4.2. Yogurt and Curd:

Yoghurt and curd are one of the widely consumed dairy products. Yogurt has a high tribological value due to its smoothness and creaminess characteristics (Miao & Lin, 2019). Yogurt has surpassed milk in popularity due to its distinct sweet and sour tastes and high nutritional content (McKinley, 2005). While testing yoghurt, frequent mouth sensations include thickness, creaminess and smoothness. The QDA and TDS sensory assessments methodologies used to investigate the effects of varied component concentrations on yoghurt perception by altering the ratio of gelatin, starch and fat in yoghurt

(Bruzzone et al.,2013). Increased gelatin content increased the feeling of thickness and gelation but decreased the judgement of creaminess. Apart from fat, the increased starch level improved the rating of smoothness. In acidic emulsion gel studies (Joyner Melito et a., 2014), it was also learned that the quantity of starch had a considerable impact on the frictional behaviour of yoghurt. Morell et al.(2017) found similar results, and tasting testing suggested that starch decreased the perception of astringency.

The effects of different component (fat, protein, casein, and whey protein) on the lubricity behaviors of stirred yoghurt were studied. The experimental findings were associated with the sensory assessment, and the necessary data were incorporated into the regression equation, which predicted the viscosity and creaminess of the yoghurt while also establishing a correlation between yoghurt composition and flavour (Sonne et al.,2014) .

Krzeminski et al.(2012) used the tribological module of a rheometer on a steel ball-rubber pad to conduct studies in a simulated oral environment, where yoghurt friction profiles were clearly varied for different lipid levels. Huc et al. (2016) also obtained that friction is substantially lower in fat-containing yoghurt than in fat-free yoghurt. The higher the fat content, the better the lubrication conditions, which was linked to fat's superior lubricating capabilities and the production of an oil film in the contact region (Tsui et al., 2016) .

43. Cheese:

As a soft solid food, cheese is composed of fat, protein, and water. The texture of the cheese, which is noted by many consumers who consume cheese on a daily basis, is an important component in appraising it (Mcewan, 1989). As a result, understanding the texture of cheese is crucial. Textural words to characterize the cheese itself (Brown et al., 2003). Chewing tests were used to examine the texture of cheese. Early in the chewing trial, low sensory acceptability (graininess, roughness, and friability) was obtained, which was ascribed to the cheese's age and low cohesiveness (Jack et al., 1994).

Creaminess was found to correlate with thickness and smoothness in oral perception. Furthermore, the sensations of thickness and smoothness were connected to friction and shear stresses during oral processing. The factors they assess may be used to calculate the creaminess evaluation score (Kokini et al., 1989). The importance of fat in the impression of eating cheese is self-evident, and the loss of fat in the structure can lead to a decline in the evaluation of cheese texture and alter the cheese consuming experience. This is especially noticeable in low-fat goods (Drake and Swanson, 1995).

By comparing texture perception between full-fat and low-fat cheeses, Gwartney et al.(2002) obtained significant variations in hardness, smoothness, viscosity, and sharpness ratings. During the oral processing of cheese, a link between creaminess and particle size was obtained (Janhoj et al., 2009). The decrease in cheese particles coincided with an increase in creaminess. Ningtyas et al. (2017) investigated the influence of cheese fat content.

4.4. **Other dairy products:** As semi-solid food models, hydrogels produced with various gelatin concentrations were utilized (Dickinson, 2012). The structure of oil-in-water emulsions was identical to that of emulsion dairy products and foods (Olivares et al., 2019).

5. Recent progress of tribology in food

The relationship between friction coefficient, viscosity and sensory perception of homogenized milk (fat content ranging from 0.06 to 8%). They found a linear relationship between perceived creaminess and friction coefficient at fat content levels greater than 1%. The coalescence of fat globules on the surface of the tongue and rubber disc was ascribed to the enhanced creaminess and hence decreased friction (Chojnicka-Paszun et al., 2012). Pasteurized milks (fat 0.1% to 4.9%) and cream cheeses (fat 0.5% to 11.6%) were chosen, and their friction coefficients were determined as a function of tribometer entrainment speed. The friction coefficients of the samples changed significantly across fat levels at low entrainment speeds creating low shear rate. They claimed that this approach could distinguish between samples with varying fat concentrations in liquid or semi-solid state (Nguyen, 2016).

6. Advantages:

It encompasses both the fluid's rheological properties as well as the surface properties of the interacting substrates. It explains the thin layer behavior of food where rheology is failed to explain. It defines the complete sensory or mouth feel perception of food product. It study's the lubricating properties of food materials such as slipperiness, creaminess, smoothness, astringency.

7. Limitations:

The oral physiological and dietary aspects are the primary limitations of employing tribology. It is ineffective for solid or particle food items. The elements influencing food oral lubricity are widely divided as food and oral system The tongue and palate are part of the oral system. Food oral lubricity is controlled by elements such as surface roughness, direction and speed of sliding/rolling action, and force between both surfaces. Apart from that, the frictional nature of food is influenced by the kind of saliva, temperature, and time spent in the mouth. Further processing (heating or microwaving prior to consumption) of designed meals may modify the tribological properties of texture-defining molecules, hence altering the sensory features of the food and its nutritional value. The equipment required to do tribological measurements is costly.

8. Future suggestions and prospects:

Overall, the current constraints and obstacles are highlighted and analyzed. This knowledge can help future designers create more realistic models and in vitro food oral processing research methodologies. Furthermore, a comprehensive instrumental system for oral food processing with significant future prospects should be established. This type of instrument may help characterize food and be easily used for assessing sensorial attributes. In dairy products it can be applied to differentiate to samples of different fat content. Need to interpret transient lubrication measurements in the context of oral processing.

9. Conclusions:

Tribology is a modern oral processing tool that is an important technology for evaluating the oral sensations of various food items such as smoothness and creaminess. Several tribometers have been produced by combining the rheometer with the texture analyzer. Oral tribology investigates the effects of fat, particle size, polysaccharide and protein on food lubrication. This also assesses food characteristics such as astringency, slipperiness, roughness, smoothness and slippery feel. This also demonstrates that the tribometer can used in conjunction with other efficient oral processing devices. Results from various tribology equipment reveal that the friction and lubrication qualities of milk and milk products samples may be assessed and linked to characteristics such as fatty feel, astringency, smoothness, roughness, and slipperiness.

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