Characteristics of flax oil and milk mixture

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Abstract: In order to develop milk products both with better taste and more health benefits, a blended system of dairy products and flax oil was studied based on the Budwig diet. The amounts of flax oil added to the pure milk or yogurt were varied and the system was fully mixed without adversely affecting the flavor. The effects of flax oil addition on the frictional and rheological properties of different dairy products were investigated, and the optimal addition ratio was determined combined with the sensory evaluation. The experimental results showed that the addition ratio of flax oil significantly affected the friction characteristics and rheological properties of dairy products, in which the friction coefficient of the mixture tended to decrease as the addition of flax oil increased, and with the added increase the viscosities of both ordinary yogurt mixture and pure milk mixture tended to increase. Furthermore, based on physical characteristics and sensory properties the optimal addition ratios of flax oil to pure milk, ordinary yogurt, and non-fat yogurt are obtained, which are 2.5wt%, 2.5wt%, and 5wt%, respectively. The study provides a quantified analysis way for the additions to the dairy products and the obtained data can be used for reference in production.

Keywords: rheology, tribology, flax oil, milk, yogurt, mixture, characteristics

DOI: 10.25165/j.ijabe.20221504.7108

Citation: Chen C S, Liu P, Li M F, Zhang X. Characteristics of flax oil and milk mixture. Int J Agric & Biol Eng, 2022; 15(4): 264–270.

1 Introduction

Eating enough high levels of omega-3 polyunsaturated fatty acids (PUFA) is greatly beneficial for reducing the risk of cardiovascular and inflammatory diseases, as well as improving brain development[1,2]. Although omega-3 PUFA has great health benefits, the average consumption of it is lower than the amount recommended by the World Health Organization[3]. Omega-3 PUFA fortified foods and beverages can provide consumers with an alternative to increasing nutrient intake[3]. Flax oil is derived from flaxseed that receives the highest amount of solar energy. It is rich in linolenic acid, which accounts for about 55% of the total fatty acids in the oil[4]. The electron group of it is rich, active, and easy to absorb oxygen and combines itself with protein into water-soluble compounds, which are protected by proteins and carried into cells to be absorbed and utilized for normal cell division. Milk protein provides essential amino acids for growth and development[5], and milk is also rich in calcium for supplementation in children and the elderly to prevent osteoporosis. Moreover, the-whey protein in milk has a high free radical scavenging ability[6]. However, for people who are born with lactose intolerance, yogurt is an alternative solution since the lactose in yogurt is cleaved by fermentation microbes and thus is easier to digest and absorb. Yogurt can not only enhance human digestion and immunity, promote appetite, and provide various vitamins, but also reduce the production of certain carcinogens and effectively prevent the occurrence of cancer[7,8].

Budwig invented the Budwig diet in 1951, and its principle is that protein with sulfur amino acids can improve the absorption and utilization of oxygen by human body cells and make the intake of fat easily soluble in water. Yogurt and milk are relatively rich in sulfur-containing amino acids, while linolenic acid is rich in active electron groups, so the oxygen can be easily absorbed in the mixture of them. Furthermore, the α-linolenic acid in flax oil can combine with sulfur-containing proteins to form a water-soluble compound to control the absorption and release of oxygen. On the other hand, the optimal ratio of omega-3 fatty acids to omega-6 fatty acids in a normal human body should be 4:1, but most people fail to meet that. It is known that the imbalance had resulted in the occurrence of many chronic diseases. Although supplementation strategies for providing a way to improve blood fatty acid levels, the assimilation rate is usually low due to difficulties in capsule swallowing or poor aftertaste[9]. The preferred way to supplement omega-3 fatty acids is by food fortification. By adding a certain amount of flax oil to milk or yogurt, *α*-linolenic acid can combine with sulfur-containing proteins to form water-soluble compounds that can control the absorption and release of oxygen. The diet supplementation strategy can not only provide supplements for omega-3 fatty acids but also prevent or slow down the occurrence of heart disease, diabetes, and other chronic diseases.

Taste sensory perception is also a very important factor for exploring the optimal addition ratios of flax oil to dairy products. During most oral physical processing fluid consumption, food no longer acts as a bulk liquid but as a film. The lubricating properties of this film may be attributed to different types of taste sensory perceptions, especially those related to fat content, and are usually described by measuring the friction between two surfaces[10,11]. Tribology (or film rheology) provides an important way to determine the properties of materials in the form of film,

Received date: 2021-10-07 **Accepted date:** 2022-03-29

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which is hard to obtain from the overall properties of the materials[12]. By changing the relative speed between the two friction surfaces, the lubricating properties of food materials can not only be analyzed in the form of bulk fluids but also be investigated for the film layer squeezed between the oral surfaces, and the film remains on the tongue surface causing taste sensory. Recent studies have shown that oral tribology has played an important role in food sensory perception[13-16]. Stribeck curve can indicate the friction between two friction surfaces in food tribology. The curve presents the relationship between the skin-friction coefficient and the relative velocity of the friction surface. A typical Stribeck curve can be divided into three parts: boundary layer area, mixed layer area, and hydrodynamic layer area[17,18].

Based on the Budwig diet therapy the appropriate amounts of flax oil added to the pure milk or yogurt were explored by experiments. Although numerous studies have confirmed the benefits of the Budwig diet in humans, there are fewer studies on the physical properties of the diet. In this study, an attempt was made to add different amounts of flax oil to plain milk or yogurt to achieve homogeneous mixtures without adversely affecting their taste, during which the frictional and rheological properties of the mixtures are measured. Each optimal addition ratio of flax oil to pure milk, ordinary yogurt, and non-fat yogurt respectively was determined by analyzing the frictional and rheological properties and sensory evaluation.

2 Materials and methods

2.1 Dairy and oil materials

Cold-pressed pure flax oil was bought from FUYIDE of Shanxi DingSheng Company, China. Ordinary yogurt (fat content 3.00%), non-fat yogurt (fat content 0.00%), and pure milk (fat content 3.60%) were purchased from San Yuan Food Company, China.

2.2 Instruments and equipment

Electric mixer (IKA, China), Homogenizer (PhD-Tech company, United States), Cooking machine (Shenzhen Xiaomei Furniture Co., Ltd., China), DHR-1 rheometer (TA, United States).

2.3 Sample preparation

Taking pure milk as an example, the maximum addition ratio was determined by pre-experiments. At 15wt% addition of flax oil, it was already difficult to mix well, requiring long time homogenization and short resting time without stratification. And if the gradient difference is too small, the experimental results are not obvious. The proportion of the flax oil added to pure milk was 2.5wt%, 5wt%, and 7.5wt%. The mixing ratio of the flax oil to ordinary yogurt was 2.5wt%, 5wt%, and 7.5wt%. The mixing ratio of the flax oil to non-fat yogurt is 5wt%, 10wt%, and 15wt%. Since dairy products need to be stored at 4℃. The mixture was stored at 4℃ for later use.

2.4 Tribological measurement

The tribological measurement was performed on DHR-1 with a full ring in plate tribology geometry. The surgical adhesive tape from 3M Transpore Surgical Tape was cut into a square, placed, and pressed on the lower plate of the DHR-1 to simulate the hydrophobic rough surface of the human tongue[19]. After each measurement, the tape was replaced, and the friction rheometer was rinsed with deionized water and wiped with special tissue paper to be dried. The sample was equilibrated at room temperature for 1 h and then to be measured. The measurement parameters were set to the duration of 600 s in logarithmic mode, 2 N for the constant force, 4℃ for the temperature, and the applied speed was 0.01 to 30.00 rad/s. The number of samples was determined according to the viscosity in triplicate for each group.

2.5 Rheology measurement

A steady-state shear measurement was used to measure the viscosity of the samples. All measurements were made in DHR-1 with a 40 mm parallel plate and the viscosity was measured with a Peltier plate to avoid sliding effects. The shear rate ranged from 0.1 s^{-1} to 100.0 s^{-1}, and all tests were performed in triplicate. Before measurement, the sample was equilibrated at room temperature for 1 h and then measured. The measurement parameters were set for a duration of 120 s, a temperature of 4℃, and a gap of 50 μm. The sample amount was determined by viscosity.

2.6 Sensory assessment

A quantitative analysis was performed with 10 subjects and 12 completely random samples. Evaluation indicators of the sensory assessment consisted of color, aroma, peculiar smell, graininess, smoothness, lipid, viscosity, and tissue state.

The score range was 0-10 points with 0 as the most dissatisfied and 10 as the most satisfied. The appropriate concentration of flax oil in each sample was determined under the condition that there was no obvious layering in the sample.

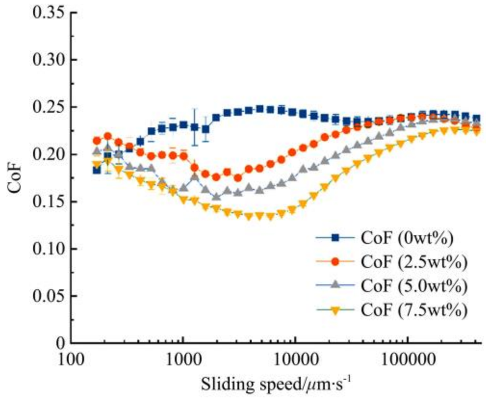
2.7 Statistical analysis

The Sample data were represented by mean values which are proceeding in SPSS 24 software (IBM SPSS Statistics, USA), and both Duncan's multiple range test and one-way analysis of variance are also accomplished by the software. The Pearson correlation coefficient by Origin Pro 8 software (Origin Lab Corporation, MA, USA) is used to analyze the relationships on the attribute parameters of tribological measurement and Rheology measurement respectively.

3 Results and discussion

3.1 Influence of flax oil addition on friction characteristics

Figure 1 shows the effect of adding different amounts of flax oil on the friction coefficient of milk, and "CoF (*Xwt*%)" stands for the coefficient of friction of a sample with a flax oil content of *Xwt*%. The addition of flax oil reduced the friction coefficient of milk, and with the increase in the concentration of flax oil, the friction coefficient decreased even more significantly, and the mouthfeel became smoother. The addition of flax oil changed the state of the pure milk friction curve. Except for the pure milk without flax oil, all other mixed liquids conformed to the three levels of the Stribeck curve as a whole, namely the boundary layer area, the mixed layer area, and the hydrodynamic force area. It can be seen that the boundary layer area is not obvious. At this stage, the friction force is controlled by the ability of the fluid to form a film between the surfaces and has nothing to do with the sliding speed[20]. As the speed increased, the fluid quickly formed a hydrodynamic film, which significantly reduced the friction (the Stribeck curve entered the mixing zone). This reduction of the friction depends on the viscosity of the sample that promotes fluid entrainment[12]. When the speed was further increased, the hydrodynamic membrane fully expanded and completely separated the surface (the hydrodynamic state). Friction is controlled by fluid viscosity and increases linearly with speed[21]. Compared with pure milk without the addition of flax oil, the friction coefficient showed a trend of rising first, followed by a slight decrease. This was due to the accumulation of particles of pure milk, which caused the friction coefficient to rise. After the film was formed, it broke quickly due to insufficient viscosity and the friction coefficient decreased. There was no significant decline as the curve tended to be stable.



Note: CoF (*X*wt%) stands for the coefficient of friction of a sample with a flax oil content of *X*wt%. The same as below.

Figure 1 Friction coefficient of pure milk with different amounts of added flax oil

Figure 2 shows the effect of adding different amounts of flax oil on the friction coefficient of ordinary yogurt. As the content of flax oil gradually increased, the friction coefficient of the mixed system showed a downward trend as a whole. For each gradient of the mixture itself, the friction coefficient always showed a trend of first decreasing, followed by increasing and ending with slightly decreasing, which is inconsistent with the classic Strobeck curve. Gabriele et al.[22] proposed a liquid gel lubrication mechanism that divides the friction curve into three areas: Zone A- at low sliding speeds, only the fluid medium can be entrained into the gap formed between the ring and the bottom plate (to reduce CoF trend); Zone B- represented by particle entrainment (increasing CoF trend); Zone C- where the sliding speed is higher allowing more particles into the gap, and CoF again shows a downward trend. As the number of particles driven into the gap increases, different layers will form. Since the thickness of the lubricating film is much larger than the size of a single particle at this stage, friction and viscosity effects will occur. The attenuation of CoF depends on the ability of the multi-component system to thicken the lubricating oil film[23].

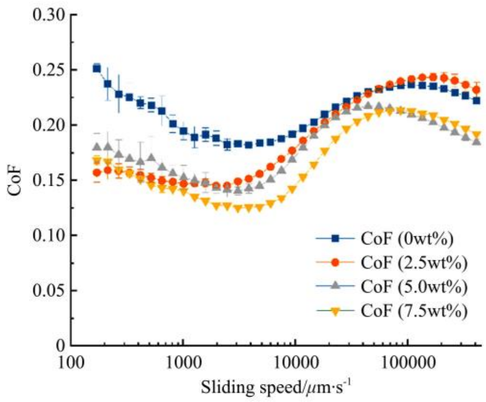


Figure 2 Friction coefficient of ordinary yogurt with different amounts of added flax oil

Figure 3 shows the effect of adding different amounts of flax oil on the friction coefficient of defatted yogurt. As the content of flax oil gradually increased, the friction coefficient of the mixed liquid showed a downward trend as a whole. For each gradient mixture of flax oil added skim yogurt itself, the friction coefficient always showed a trend of first declining, then rising, and slightly declining at last. For the non-fat yogurt itself, the friction coefficient did not increase, which may be due to only fluid medium entering the gap formed between the ring and the bottom plate without any particle entrainment.

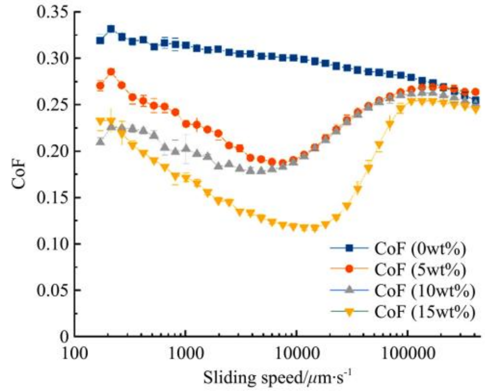


Figure 3 Friction coefficient of non-fat yogurt with different amounts of added flax oil

Figure 4 shows the effect of fat content on the friction coefficient of yogurt. When the flax oil content was set at 0.0wt%, the friction coefficient of ordinary yogurt was significantly different from that of non-fat yogurt. When the flax oil content was 5wt%, the two also had a significant difference among the A region proposed by Gabriele et al. At low sliding speeds, only the fluid medium can be entrained into the gap formed between the ring and the bottom plate. The consistency of ordinary yogurt was lower than that of non-fat yogurt. At the same time, it may be accompanied by whey precipitation and enter the gap more easily[24]. The more fluid medium entered, the more the friction coefficient decreased. Through the comparison of ordinary yogurt and non-fat yogurt, it can be concluded that fat content is the main factor affecting the friction coefficient of yogurt.

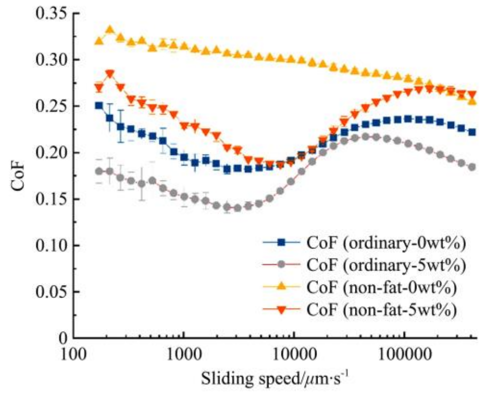
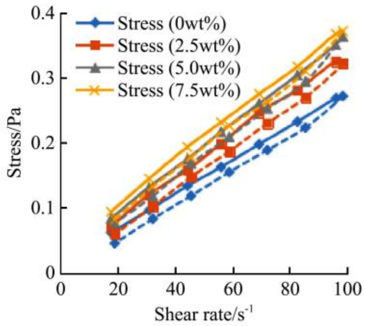


Figure 4 Comparison of the friction coefficient between ordinary yogurt and non-fat yogurt

3.2 Influence of flax oil addition on rheological properties

Figures 5 and 6 show the effect of the added flax oil on the rheological properties of pure milk. "Stress (*Xwt*%)" and "Viscosity (*Xwt*%)" in the figures represents respectively the shear stress and viscosity of a sample with an oil content of *Xwt*%. With the gradual increase in the content of flax oil, the shear stress and viscosity of the mixed liquid showed an overall upward trend. For each gradient of the mixture itself, the shear stress and viscosity were significantly different in the speed-up and speed-down phases. It can be seen from Figure 5 that the shear stress of the mixed liquid gradually increased with the increase in the shear rate. When the shear stress reached its maximum value, the shear rate began to decrease, and the shear stress decreased accordingly. The trend of the whole curve was the shear stress in the Newtonian fluid and was linearly related to the sheer speed. Additionally, the yogurt had hysteresis in the rise and fall curves because the structure of the liquid cannot be restored to a balanced state after being damaged. The thixotropic ring is composed of an acceleration curve and a deceleration curve, which is a typical feature of a thixotropic fluid[25,26]. The larger the area of the thixotropic ring, the longer it took for the material to recover after being compressed. Table 1 shows that as the amount of flax oil added was gradually increased, the area of the thixotropic ring gradually increased. The addition of flax oil reduced the recovery of the mixed liquid to a certain extent. This may be due to the increase in the viscosity of the mixed liquid caused by the addition of flax oil, which resulted in poor recovery. It can be seen from Figure 6 that as the shear rate increased, the apparent viscosity gradually decreased from the initial maximum value which can be determined that the mixture was not a Newtonian fluid. When the shear rate was large to a certain extent, the viscosity difference of the mixed liquid gradually decreased and dropped to its lowest value. Although the two curves had similar trends, there was hysteresis. The apparent viscosity should be closest to the oral environment when the shear rate is 50 s^{-1}[27]. It can be seen from Table 1 that with the continuous increase of added flax oil, the apparent viscosity value continued to increase, indicating that the addition of oil had a certain impact on the taste. The Herschel-Bulkley model was used to fit the shear scan curve[28]. The model can be represented by the formula $\sigma=\sigma_0+K\gamma^n$, where, σ represents the shear stress, Pa; σ_0 represents the yield stress, Pa; K represents the consistency coefficient, Pa.s^n; γ represents the shear rate, s^{-1}; n represents the flow behavior index[29]. The fitting correlation coefficients of all samples were greater than 0.9, indicating that the model can fit the flow curve of dairy products well. The results are listed in Table 1.



Note: "Stress (*X*wt%)" and "Viscosity (*X*wt%)" in the figures represents respectively the shear stress and viscosity of a sample with an oil content of *X*wt%. The same as below.

Figure 5 Shear stress of pure milk with different amounts of added flax oil

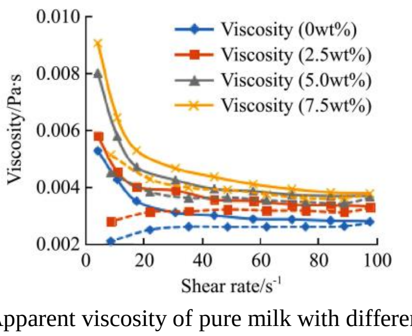


Figure 6 Apparent viscosity of pure milk with different amounts of added flax oil

Table 1 Rheological parameters of a mixed system of pure milk and flax oil

Sample name	σ_0/Pa	k/Pa·s^n	n	ΔA/Pa·s^{-1}	η_{50}/Pa·s
Pure milk (0.0wt%)	0.00527	0.00297	0.984	1.785	0.00296
Pure milk (2.5wt%)	0.00635	0.00377	0.979	1.930	0.00325
Pure milk (5.0wt%)	0.00711	0.00407	0.952	2.051	0.00357
Pure milk (7.5wt%)	0.00723	0.00485	0.931	2.078	0.00362

Note: σ_0 represents the yield stress, Pa; k represents the consistency coefficient, Pa s; n represents the flow behavior index; ΔA represents the lagging ring area; η_{50} represents the Viscosity (at 50 s^{-1}).

Figure 7 and Figure 8 show the effect of adding flax oil on the rheological properties of ordinary yogurt. The shear stress and viscosity of the mixture exhibited an overall upward trend as the flax oil content was gradually increased. It can be seen from Figure 7 that the shear stress of the mixed liquid gradually increased with the increase of the shear rate, and the area forming the thixotropic ring gradually increased with the addition of linseed oil, indicating that the recovery of the mixed liquid was reduced by the presence of oil to a certain extent. It can be seen from Figure 8 that when the shear rate increased, the apparent viscosity gradually decreased. As the shear rate became larger and larger, the viscosity difference of the mixed liquid gradually turned smaller until it reached its lowest value. The fitting correlation coefficients of all samples were greater than 0.9, indicating that the Herschel-Bulkley model can fit the dairy product flow curve well. The results are listed in Table 2. can be seen from Table 2 that with the continuous increase of the added amount of flax oil, the apparent viscosity value continued to increase, indicating that the

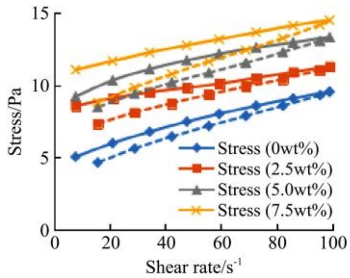


Figure 7 Shear stress of ordinary yogurt with different amounts of added flax oil

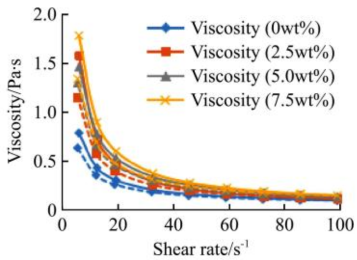


Figure 8 Apparent viscosity of ordinary yogurt supplemented with different amounts of flax oil

Table 2 Rheological parameters of the mixture system of ordinary yogurt and flax oil

Sample name	σ_0/Pa	k/Pa·s^n	n	ΔA/Pa·s^{-1}	η_{50}/Pa·s
Ordinary yogurt (0.0wt%)	2.221	0.430	0.611	79.692	0.15271
Ordinary yogurt (2.5wt%)	4.877	0.556	0.522	114.823	0.19912
Ordinary yogurt (5.0wt%)	4.985	0.999	0.470	141.741	0.23841
Ordinary yogurt (7.5wt%)	5.634	0.628	0.572	177.103	0.25987

Note: σ_0 represents the yield stress, Pa; k represents the consistency coefficient, Pa s; n represents the flow behavior index; ΔA represents the lagging ring area; η_{50} represents the Viscosity (at 50 s^{-1}).

addition of oil had a certain effect on the taste. The magnitude of the yield stress of yogurt was closely related to the degree of sensory softness. The yield stress became harder to reduce as it grew larger. The yield stress of the yogurt increased with the increase in the amount of flax oil, indicating that the texture became harder and the liquid viscosity was increased to a certain extent.

Figure 9 and Figure 10 show the effect of the added flax oil on the rheological properties of non-fat yogurt. As the content of flax oil gradually increased, the shear stress and viscosity of the mixture showed a downward trend as a whole. It showed that the addition of oil increased the lubricating performance of the mixed liquid. It can be seen from Figure 9 that as the shear rate increased, the shear stress of the mixed liquid gradually decreased, and the shear stress continued to decrease when the decreasing momentum started to reduce, but the trend of the rate of decrease and the rate of increase was different, which may be due to the texture of non-fat yogurt being hard and can be reflected in the value of the yield stress. Due to the hard texture, the non-fat yogurt did not return to its original status after being cut, which just verified the large area of the thixotropic ring formed by the non-fat yogurt. The area of the thixotropic ring formed by the two curves is shown in Table 3. Comparing the non-fat yogurt with and without flax oil, it can be seen that the addition of oil could significantly improve the recovery of non-fat yogurt. It was estimated that the addition of 2.5wt% oil increased the recovery of non-fat yogurt by more than double. As the addition of flax oil continued to increase, the area of the thixotropic ring decreased, indicating that the addition of oil enhanced the recovery performance of the mixed solution to a certain extent, but the difference between the gradients was not obvious. It can be seen from Figure 10 that the increase in shear rate led to a decrease in apparent viscosity. The fitting correlation coefficients of all samples were greater than 0.9, indicating that the Herschel-Bulkley model can fit the dairy product flow curve well. The results are listed in Table 3. With the continuous increase of the added amount of flax oil, the apparent viscosity value continued to decrease indicating that the addition of oil had a certain effect on the taste but the difference between the gradients was not obvious. The larger the value of *n*, the weaker the shear-thinning characteristic of the yogurt during the shear scanning process and the rougher the taste was. The shear-thinning resistance of the liquid was becoming stronger as the *n* value got smaller. The value of *n* and the taste of non-fat yogurt were the smallest and smoothest among the three dairy products.

In summary, the rise and fall curves of the mixed liquid had hysteresis in the shear rate and shear stress curves of the three kinds of dairy products which were caused by the failure to restore balance immediately after the liquid structure was damaged. The formation of a thixotropic ring between the speed-up curve and the speed-down curve was a typical feature of thixotropic fluids. Generally, the area enclosed by the upper and lower curves represented the thixotropic viscosity. The larger the area of the thixotropic ring, the greater the viscosity change of the system would be after the external force was applied, and the longer it could take for the system to return to its original state after the external force was removed, which means that the thixotropic reactive material undergoes a re-densification process when it is static after a long period of shearing[30,31]. It can be preliminarily determined that the three kinds of dairy products should be thixotropic fluids.

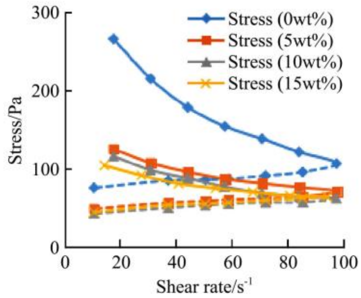


Figure 9 Shear stress of non-fat yogurt with different amounts of flax oil

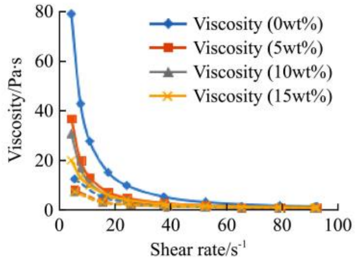


Figure 10 Apparent viscosity of non-fat yogurt with different amounts of flax oil added

Table 3 Rheological parameters of the mixed system of non-fat yogurt and flax oil

Sample name	σ_0/Pa	*k*/Pa·s	*n*	ΔA/Pa·s^{-1}	η_{50}/Pa·s
Non-fat yogurt (0wt%)	26.432	72.848	0.223	10089.322	3.40237
Non-fat yogurt (5wt%)	24.968	26.375	0.199	4164.683	1.86743
Non-fat yogurt (10wt%)	22.685	19.364	0.191	3142.821	1.74984
Non-fat yogurt (15wt%)	22.117	10.264	0.121	2941.175	1.49003

Note: σ_0 represents the yield stress, Pa; *k* represents the consistency coefficient, Pa s; *n* represents the flow behavior index; ΔA represents the lagging ring area; η_{50} represents the Viscosity (at 50 s^{-1}).

The apparent viscosity of the three types of dairy products decreased gradually from the maximum with the increase in shear rate. The maximum value was the critical point at which the rotor overcame the maximum stress of the dairy products, causing their original structure to crack. The shear stress at this time is the yield stress of the gel in them[32]. At a lower shear rate, the three types of the dairy product had a relatively high apparent viscosity which decreased as the shear rate increased. It is shown that there could be shear thinning in three types of dairy products.

3.3 Influence of flax oil addition on flavor

Figure 11 shows the effect of varying amounts of flax oil addition on the flavor of pure milk. The sample number is composed of a random number of three digits, e.g., "420 (*Xwt*%)" represented the sample "420" with an oil content of *Xwt*%. Among the eight indicators, the "organization status" was the least affected, while the "grainy" and "peculiar smell" were the most affected. The 2.5wt% addition of flax oil into pure milk had a relatively less impact among them, which was consistent with the analysis of tribology and rheology.

Figure 12 shows the effect of varying amounts of flax oil addition on the flavor of ordinary yogurt. Among the eight indicators, "organization status" and "slippery" were least affected, and "lipid" and "Consistency" were most influenced. The ordinary yogurt with an additional amount of 2.5wt% flax oil had a relatively small effect among them. Figure 13 shows the effect of varying amounts of flax oil addition on the flavor of non-fat yogurt. Among the eight indicators, "slippery" was the least affected, and "Lipid" and "Grainy" were the most affected. The addition amount of 5wt% flaxseed oil into non-fat yogurt had less impact on the flavor.

As shown in Table 4, the varied amount of flax oil addition for three kinds of dairy products had a greater or lesser impact on the flavor. The average score was derived from each indicator. The larger the amount of added flax oil, the lower the average score would be. Flax oil is rich in fatty acids and has a distinctive flavor, which affects the flavor of dairy products to a certain extent. Experiments show that the varied amount of flax oil addition would bring an impact on the flavor of yogurt or milk in different degrees, so the added amount of flax oil should be controlled below 5wt% at least.

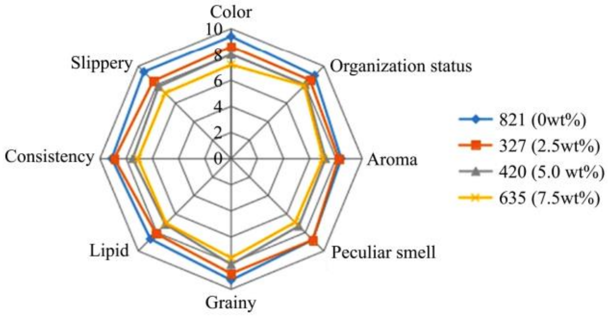


Figure 11 Influence of flax oil on the flavor of pure milk

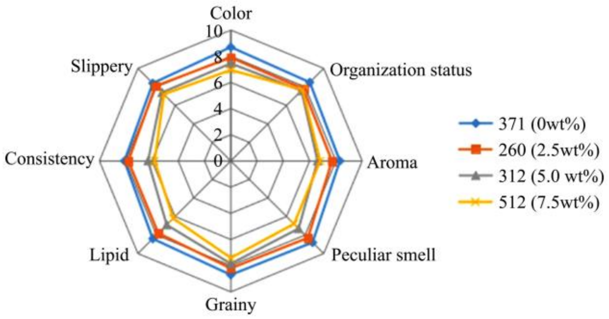


Figure 12 Influence of flax oil on the flavor of ordinary yogurt

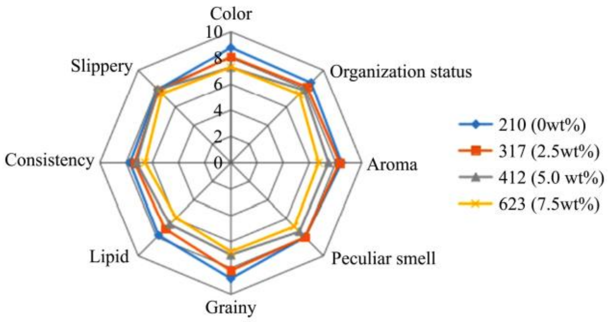


Figure 13 Influence of flax oil on the flavor of non-fat yogurt

Table 4 Effects of different supplemental flax oil levels organoleptic score

Species	Pure milk				Ordinaryyogurt				Non-fat yogurt			
Sample serial number	821	327	420	635	371	260	312	512	210	317	412	623
Addition of oil/wt%	0.0	2.5	5.0	7.5	0.0	2.5	5.0	7.5	0.0	5.0	10	15
Color	9.40	8.60	8.00	7.20	8.70	7.90	7.45	6.95	8.80	8.10	7.30	7.30
Peculiar smell	8.80	8.80	7.30	6.90	8.80	8.30	7.30	6.80	8.00	8.00	7.40	6.85
Aroma	8.40	8.20	7.20	7.00	8.30	7.70	6.60	6.80	8.45	8.30	7.45	6.70
Slippery	9.40	8.40	7.80	7.10	8.40	8.10	7.40	7.20	7.90	7.80	7.90	7.45
Grainy	9.30	8.80	8.10	7.60	8.70	8.20	7.85	7.40	8.80	8.20	7.00	6.75
Lipid	8.70	8.10	7.10	7.00	8.40	7.80	6.90	6.20	7.80	7.10	6.60	5.90
Consistency	9.10	8.90	7.50	7.10	8.10	7.80	6.30	5.80	7.70	7.35	7.20	6.55
Organization status	9.00	8.50	8.00	7.90	8.5	7.80	7.60	7.70	8.65	8.20	7.85	7.40
Average score	9.01	8.54	7.63	7.23	8.49	7.95	7.18	6.86	8.26	7.88	7.34	6.86

4 Conclusions

A series of physical properties and sensory analyses were carried out in this study by mixing different kinds of commercially available dairy products with different gradients of flax oil without stratification.

In the tribological analysis, the friction coefficient of different mixtures with the sliding rate was discussed: the friction curve of the pure milk and flax oil mixture basically conformed to the classic Stribeck curve, and the friction coefficient of the pure milk changed significantly after it was added flax oil. The friction curves for both ordinary yogurt and non-fat yogurt mixture with flax oil are relatively more in line with the liquid gel lubrication mechanism proposed by Gabriele et al.[22]

In the rheological analysis, a series of analyses were carried out for the shear stress and apparent viscosity of different milk-oil mixtures against the shear rate, and the shear stress of pure milk and ordinary yogurt both gradually increased with the increase of the shear rate. However, the shear stress of non-fat yogurt, which was added to flax oil, decreased with the increase of the shear rate. Moreover, the apparent viscosity of the three types of dairy products decreased gradually with the increase in the shear rate, and there was a phenomenon of shear thinning.

The flavor of the three types of dairy products with different flax oil gradients was evaluated using eight indicators of color, aroma, peculiar smell, smoothness, granularity, lipid, consistency, and tissue state in the sensory evaluation. In general, the amount of flax oil added was preferably less for better flavor, but it would have a marginal effect on the flavor of the dairy product when the addition was less than 5wt%.

The effects of flax oil addition on the frictional and rheological properties of different dairy products were explored with a series of experiments and data analysis in the study, and the optimal addition ratios of flax oil in pure milk, ordinary yogurt, and non-fat yogurt were found out by combining physical characteristics and sensory properties. The study probes into the quantified analysis way for dairy products with flax oil addition and provides the data to support the construction of a dairy-flax oil blended food system as well as the Budwig diet.

Acknowledgments

The authors acknowledge that this work was financially supported by the Natural Science Foundation of Beijing (Grant No. KZ20110011013).

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