Antioxidant effects of plant ingredients on a dairy lipid base

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Abstract

Introduction. This study aimed to evaluate the antioxidant effects of plant ingredients on the stability and properties of high-fat milk-based mixtures during storage.

Materials and methods. The functional and technological properties of cocoa and sesame fibre in a lipid medium, as well as the quality indicators of the resulting mixtures during storage at (4±2) °C and (20±2) °C were assessed using standard analytical methods. These included determination of the fat-holding capacity and swelling degree of cocoa and sesame fibre, as well as measurement of peroxide and acid values of the dairy lipid base with and without added plant antioxidants over 16 days of storage.

Results and discussion. According to the obtained results, the highest fat-holding capacity and swelling capacity in cream with a 15% fat content were recorded for cocoa fibre, reaching 3.5±0.1 g/g and 2.8±0.1 g/g, respectively. In contrast, the corresponding values for sesame fibre were 1.9±0.1 g/g and 1.1±0.1 g/g. These differences may be attributed to the higher content of insoluble dietary fibre and phenolic compounds in cocoa fibre, which enhance its interaction with the lipid phase.

The effect of cocoa and sesame fibre on the spoilage rate of the lipid dairy mixture during storage at (4±2) °C was investigated. In the control sample, the peroxide value doubled by the 16th day of storage compared with the initial level. In samples containing cocoa or sesame fibre, an antioxidant effect was observed; by the end of the storage period, the peroxide value was 1.05-fold and 1.12-fold lower, respectively, than that of the control.

The influence of the antioxidant dihydroquercetin on changes in peroxide and acid values of the lipid dairy base containing cocoa or sesame fibre during 16 days of storage at (20±2) °C and (4±2) °C was also evaluated. In the control sample, the lipid dairy base supplemented with 0.03% dihydroquercetin exhibited an increase in peroxide value from 0.94 mmol ½ O/kg on day 1 to 1.30 mmol ½ O/kg on day 16, indicating a slow accumulation of primary oxidation products. In experimental samples containing plant ingredients, a slightly lower rate of peroxide value increase was observed. With increasing storage time, the acid value of the lipid–plant mixtures gradually increased, with the most pronounced increase occurring in the control sample.

Conclusions. The incorporation of cocoa or sesame fibre in combination with dihydroquercetin into dairy lipid base mixtures reduces oxidative and hydrolytic deterioration of the lipid fraction during storage.

Introduction

A wide range of natural and synthetic antioxidants is currently available (Singh et al., 2025; Yildiz et al., 2025). Antioxidants are of particular importance in the modern dairy industry, where consumers increasingly demand products with extended shelf life and minimal use of artificial additives (Gubsky et al., 2025). The application of effective natural antioxidants or plant-derived ingredients with antioxidant activity not only enhances product quality but also aligns with market expectations regarding safety and environmental sustainability (Stabnikova et al., 2024).

As reported by Alvarado-Martinez et al. (2020), concerns regarding the potential toxicity of synthetic antioxidants have intensified interest in natural alternatives. Numerous studies confirm that natural antioxidants generally lack carcinogenic and mutagenic properties, making them a safer and more promising option compared with synthetic compounds.

In dairy processing, natural antioxidants are widely used to inhibit lipid oxidation, thereby preserving sensory attributes, extending shelf life, and protecting nutritional value (Abd El-Aziz, 2023; Stobiecka et al., 2022). Enhancement of the endogenous antioxidant system of dairy products, particularly lipid-based matrices, can be achieved through the incorporation of phytochemical compounds such as vitamins C and E, polyphenols, and carotenoids (Christaki et al., 2021; Meléndez-Martínez et al., 2022; Wiley et al., 2024).

Numerous studies have shown that certain natural components, including plants and their processed products, can stabilize fats against oxidation while also exhibiting antimicrobial activity (Abd El-Aziz et al., 2023; Santos et al., 2023). The prevention of oxidative and microbiological spoilage in fat-containing products is achieved through the application of various technological approaches (Stobiecka et al., 2022).

The modern food industry requires the identification of natural components capable of extending shelf life and improving the quality of high-fat dairy products. Among promising natural sources of antioxidants with additional antimicrobial properties are plant-derived ingredients, particularly cocoa fibre and sesame fibre.

Cocoa fibre is free of preservatives and consists of cocoa shell and cocoa nibs ground during the production of cocoa butter or cocoa powder, in a non-alkalized form. It contains 6–7 times more antioxidants and magnesium than most other plant products, while being low in fat. In addition to their functional properties, dietary fibres possess specific technological characteristics, enabling the production of foods with moderately viscous textures. Cocoa fibre is particularly rich in phenolic compounds, including flavanols, procyanidins, chlorogenic acids, and alkaloids (Sánchez et al., 2023). Therefore, cocoa fibre can be regarded as a carbohydrate–protein complex that not only provides valuable nutrients but also exhibits antioxidant activity (Anoraga et al., 2024).

Sesame fiber is a natural product and a source of dietary fiber, micro- and macronutrients, mono- and polyunsaturated fatty acids (Chen et al., 2023). Sesame fiber is a valuable source of natural antioxidants that effectively protect biomolecules from the action of reactive oxygen species and free radicals. The main antioxidant components are phenolic compounds, namely sesamol, sesamin, and sesamolin, which belong to the class of lignans inherent to the seeds of *Sesamum indicum* L. These substances are capable of binding free radicals, inhibiting chain reactions of lipid peroxidation, and stabilizing cell membranes (Lee et al., 2021). Due to the presence of hydroxyl and methoxyl groups, these compounds exhibit high electron-donor capacity, forming stable radical structures that enhance the antioxidant effect. The antioxidant action of sesame fiber is realized through a dual mechanism – physical adsorption of oxidation products and chemical neutralization of free radicals (Park et al., 2024). Thus, sesame fiber is a promising functional ingredient for improving the oxidative stability of fat-containing food products.

In the food industry, antioxidants with proven efficacy and well-studied effects on various fat bases, including dairy, are widely used. Dihydroquercetin (DHQ), also known as taxifolin (2,3-dihydro-3,5,7-trihydroxy-2-(3,4-dihydroxyphenyl)-4H-1-benzopyran-4), belongs to the class of bioflavonoids and exhibits a broad range of biological, antioxidant, and vitamin-like activities (Patil et al., 2025). DHQ contains five active hydroxyl groups in its structure and is considered a P-vitamin compound, acting as a catalyst in numerous biochemical processes. Its antioxidant and capillary-protective effects are reported to be 3–5 times greater than those of commonly used preparations (Unver et al., 2024). Dihydroquercetin is a plant extract obtained from the roots of larch and is found in Chinese yew. The substance is a flavonoid and a representative of the P-vitamin group, typically available as a fine white to light-yellow powder (El-Hadad et al., 2020; Muramatsu et al., 2020).

A technology for producing functional soybean yogurt containing blueberries, stevioside, and dihydroquercetin is known. It has been established that dihydroquercetin exhibits the highest antioxidant activity compared to other antioxidants (Bal-Prylypko et al., 2025).

In addition to the effectiveness of the above-mentioned antioxidants, there are technological challenges associated with the use of plant polyphenols in food systems, related to their low solubility in the medium, chemical lability, tendency to polymerization, and loss of biological activity. Furthermore, the ability of plant polyphenols to retain their properties in complex food systems with increased fat content, as well as their impact on technological processes in dairy production, is insufficiently studied. In particular, literature sources contain studies indicating that some polyphenols are capable of inhibiting the development of starter culture microorganisms (Yang et al., 2023). Considering the aforementioned, it is relevant to study the antioxidant effect of plant ingredients on the dynamics of spoilage of milk-based mixtures with increased fat content during storage. A promising solution to this task may be the use of cocoa and sesame fiber in combination with the antioxidant dihydroquercetin as functional food components of the mixtures.

Materials and methods

Materials

The basis for the preparation of experimental samples of lipid milk base mixtures was cream pasteurized at a temperature of (85±2) °C with a holding time of 15-20 s, homogenized at a pressure of 10-15 MPa, which had a liquid, homogeneous consistency without fat lumps or protein flakes; a slightly sweet, clean taste, free from foreign flavors and odors not characteristic of fresh cream, and the following physicochemical indicators: mass fraction of fat 15%, protein – 2.9±1%, carbohydrates – 4.2±0.3%, mineral substances (mg): sodium – 40, potassium – 124, calcium – 90, magnesium – 10, phosphorus – 83, iron – 0.1, carotene – 0.03, vitamins (mg): A – 0.06, B2 – 0.1, PP – 0.2, C – 0.5, titratable acidity 17±1 °T, density 1010 kg/m^3.

Cocoa fiber or sesame fiber was added to the lipid milk base for 3.0% – a rational dosage established by previous physicochemical and organoleptic studies. Mixing was carried out at a temperature of 45 °C followed by pasteurization of the mixture at 85-87 °C (Grek et al., 2025).

To determine the shelf life, samples of the lipid milk base with cocoa or sesame fiber and the natural antioxidant dihydroquercetin were produced. Samples without the addition of plant ingredients, as well as samples with and without the antioxidant, were used as reference (control). According to the manufacturer's recommendations, the amount of dihydroquercetin added to the lipid milk base was 0.03% of the fat mass. Dihydroquercetin was dissolved in cream, after which the resulting solution was added to the container before pasteurization.

Cocoa fiber has the following chemical composition, %: fat – 2.5, protein – 17.0, carbohydrates – 0.7, and salt – 0.1. The main mass consists of 72.0% fiber, including 61.0% insoluble and 11.0% soluble dietary fiber. According to consumer characteristics, the product is a brown powder with a homogeneous structure and an intense chocolate taste and aroma, without foreign flavors (Rojo–Poveda et al., 2020).

Sesame fiber (“Richoil”, Ukraine) has the following chemical composition, %: protein – 48.9, carbohydrates – 29.1, fat – 11.2, dietary fiber – 7.8, moisture – not more than 8.

Dihydroquercetin (Bioflavid LLC) was dissolved in distilled water, after which the resulting solution was added to the container before pasteurization.

Methods

Standardized and validated methods for analyzing technological properties and quality indicators were applied during the research process, ensuring the reliability of the obtained results and achievement of the stated objective.

Technological properties of cocoa and sesame fiber

The fat-binding capacity of cocoa or sesame fiber mixed with cream with 15% fat content was determined using the centrifugation method at a temperature of 20±2 °C (Wagner et al., 2024).

The swelling capacity of cocoa or sesame fiber was determined by the gravimetric method, which involves determining the change in mass after immersion in cream with 15% fat content for the corresponding time (Grek et al., 2022). Quantitatively, this indicator is characterized by the swelling degree (K), which reflects the relative increase in the mass of the system. The study was carried out at a temperature of 20±2 °C.

Indicators characterizing oxidation of lipid milk base mixtures with cocoa or sesame fiber and antioxidant

The peroxide value, which characterizes the amount of peroxides and hydroperoxides, was determined by the iodometric method. The principle of the method consists in the release of iodine from potassium iodide under the influence of peroxide compounds of fat. The peroxide value is expressed in millimoles of ½ oxygen per kilogram (mmol ½ O/kg) (Pashaei, 2025).

The acid value was determined by titration. This indicator reflects the concentration of free fatty acids in 1 g of fat and is measured as the volume of 0.1 N KOH solution required for complete neutralization. To calculate the final value of the acid value, the volume of 0.1 N alkali solution used for titration of milk fat was multiplied by a factor of 2 (Pashaei, 2025).

Statistical Analysis

Data were expressed as means±standard deviations for triplicate determination. Statistical analysis was performed using Microsoft Excel 2007.

Results and discussion

Technological properties of cocoa and sesame fiber

At the first stage, the fat-binding capacity and the swelling degree of sesame and cocoa fiber in cream with 15% fat content at a temperature of 20±2 °C were determined. The results of the research are presented in Table 1.

Table 1

Characteristics of cocoa and sesame fibers

Parameters	Type of fiber	
	Cacao	Sesame
Fat-binding capacity of fiber, g/g	3.5±0.1	2.8±0.1
Swelling degree, g/g	1.9±0.1	1.1±0.1

According to the values presented in Table 1, the highest fat-binding capacity in cream with a mass fraction of fat of 15% was recorded for cocoa fibre 3.5±0.1 g/g. At the same time, this sample is characterized by an increased swelling degree 1.9±0.1 g/g. The obtained effect is due to the specific chemical composition of cocoa fibre and is consistent with the data provided by other researchers for similar systems (Delgado-Ospina et al., 2021). For comparison, the fat-binding capacity of sesame fibre is lower by 0.7±0.1 g/g, and the swelling degree is lower by 0.8±0.1 g/g, respectively. In cream with 15% fat content, cocoa fibre better retains fat and stabilizes the emulsion. This is explained by the presence of surface-active compounds (polyphenols and residues of cocoa butter), which promote the formation of a stable "fat-water-solid phase" system (Merachli et al., 2021).

The swelling kinetics of sesame and cocoa fibre were studied at a temperature of 20±2 °C in cream with 15% fat content for 60 minutes (Figure 1).

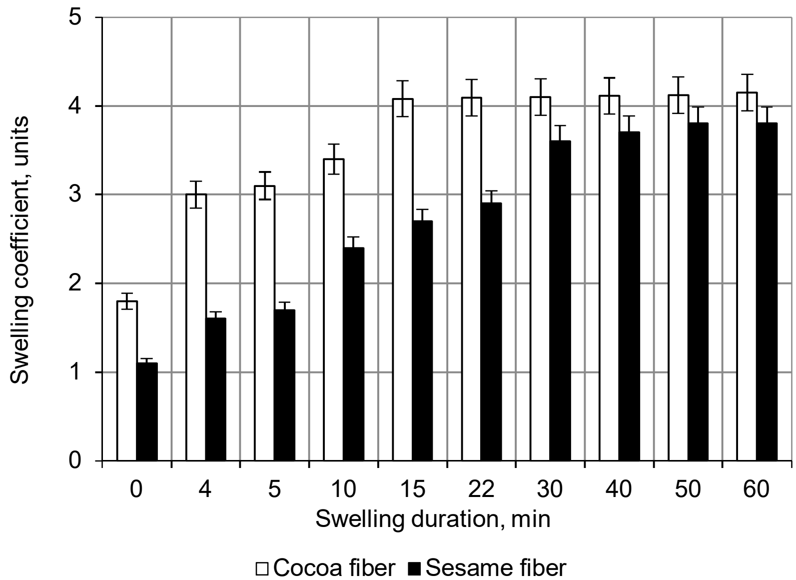

Figure. 1. Swelling kinetics of sesame and cocoa fibre at 20±2 °C in cream with 15% fat content

According to the research results (Figure 1), the most intensive swelling of all fibre types occurs within the first 15 minutes (for cocoa fibre, and 30 minutes for sesame fibre). The maximum swelling coefficient in cream reaches 4.10±0.02 units for cocoa fibre and 3.8±0.01 units for sesame fibre, respectively. The rational swelling duration for all types of fibre ranges from 15 to 30 minutes. An increase in the contact time with cream to 60 minutes leads to a slowdown in the swelling dynamics. Because of the volume increase of fibre during swelling in the spatial network, tension likely arises, which leads to the cessation of swelling (Van de Velde et al., 2024).

Temperature significantly affects the intensity and degree of swelling of plant ingredients in various technological media. The influence of temperature on the swelling degree of cocoa and sesame fibres in cream with a fat mass fraction ranging from 10% to 20% was specified. The highest swelling coefficients were observed at (45±5) °C, reaching 5.41±0.1 units for cocoa fiber and 4.10±0.1 units for sesame fiber, respectively. This is consistent with the findings of Grek et al. (2025).

Changes in milk fat quality during storage were monitored by measuring the amount of hydrolysis and oxidation products. These compounds do not immediately deteriorate organoleptic properties; however, they indicate significant degradation of the studied samples. Thus, measuring peroxide accumulation in the lipid milk base with fibre makes it possible to predict oxidation stability before consumer characteristics deteriorate.

Effect of cocoa and sesame fiber on changes in the peroxide value of milk lipid-based mixtures

An assessment of the influence of cocoa and sesame fibre on the spoilage rate of lipid milk base mixtures was conducted. The experimental samples were stored at a temperature of (4±2) °C. The effect of plant ingredients on the peroxide value of lipid–milk base mixtures during storage at (4±2) °C is shown in Figure 2.

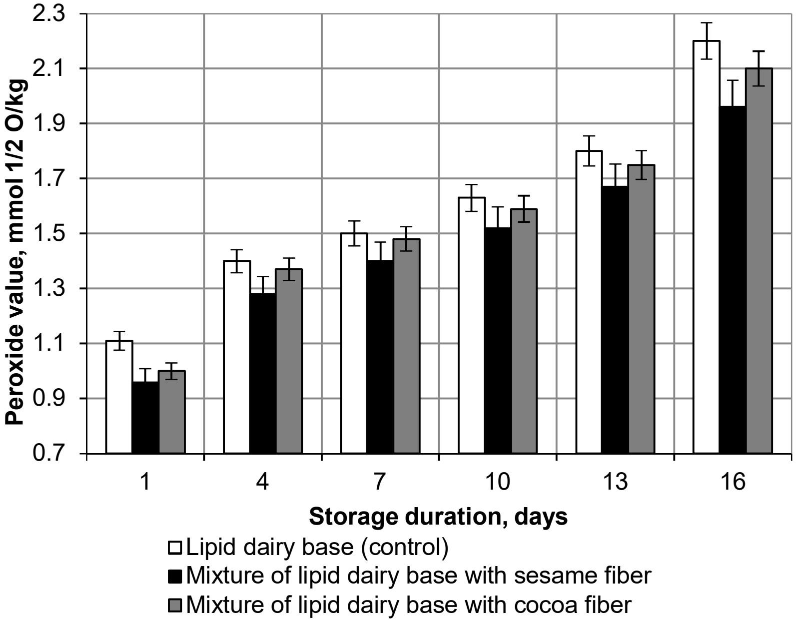

Figure 2. Influence of cocoa and sesame fibre on peroxide value of lipid–milk base mixtures during storage at (4±2) °C

According to the research results, the peroxide value in the control sample increased continuously throughout the storage period, doubling by the 16th day compared to its initial level. The sample with cocoa fibre demonstrates a noticeable antioxidant effect. By the end of the storage period, its peroxide value was 1.05 times lower than the control, confirming the antioxidant effect. This result indicates moderate effectiveness in inhibiting primary oxidation. These observations are consistent with the findings of Soares and Oliveira (2022) and Benítez et al. (2023), which showed that cocoa by-products, due to their high fibre and polyphenol content, slow down oxidative processes in lipid systems.

The lipid milk base sample with sesame fibre had a peroxide value 1.12 times lower than the control sample and 1.07 times lower than the sample with cocoa fibre by the end of the storage period. The higher antioxidant activity of sesame fibre (the peroxide value on day 16 is) is explained by several factors. It contains a significant amount of phenolic compounds such as sesamol, sesamin, and sesamolin, which have high antiradical activity and can stabilize free radicals formed during lipid oxidation (Abbas et al., 2022; Morsy et al., 2022). The structural features of sesame fibre, particularly the presence of hydrophilic and hydrophobic fractions, allow it to interact effectively with the lipid phase, providing local inhibition of oxidation processes. Similar results were reported by Morsy et al. (2022), where sesame extracts and by-products effectively reduced primary oxidation indicators in lipid systems. Thus, comparison with literature data confirms that both fibres (cocoa and sesame) exhibit antioxidant activity; however, sesame fibre demonstrates a higher ability to inhibit lipid oxidation due to a combination of high phenolic content, the ability to chelate catalytic metal ions, and effective interaction with the lipid matrix.

The obtained results indicate that the antioxidant potential of plant ingredients is limited, which necessitates the introduction of more effective antioxidants into lipid milk base mixtures with fibre to prevent oxidative processes during storage.

Effect of dihydroquercetin on changes in the peroxide value of milk lipid-based mixtures with cocoa or sesame fiber during storage

At the next stage, the effect of the antioxidant dihydroquercetin, at the manufacturer-recommended concentration, on the spoilage rate of the lipid milk base enriched with cocoa or sesame fibre was studied. The experimental samples were stored at (4±2) °C for 16 days. The results of the study are presented in Figure 3.

By the end of storage, the peroxide values of the lipid milk base mixtures containing plant ingredients and dihydroquercetin (DHQ) slightly decreased compared to the values on the 13th day, likely due to the transformation of primary oxidation products into secondary ones (Li et al., 2025). During this period, the difference between the peroxide values of the control and experimental samples ranged from 0.4% to 1.8%, indicating a slowdown in oxidation processes in the presence of plant components (Oboulbiga et al., 2023; Yin et al., 2024). The more pronounced antioxidant effect of the sample with sesame fibre is explained by the presence of specific lignans such as sesamol, sesamin, and sesamolin, – which have high thermal stability and effectively inhibit both the initiation and propagation of lipid oxidation chain reactions (Oboulbiga et al., 2023; Yin et al., 2024).

Temperature is a key factor influencing the shelf life of lipid milk bases (Khan et al., 2020; Yan et al., 2025). Higher temperatures accelerate oxidative and hydrolytic reactions in milk fat products, while lower temperatures slow these processes. Therefore, it is important to study the oxidation kinetics of lipid milk base mixtures under auto-oxidation conditions, particularly at elevated storage temperatures. To evaluate the effect of dihydroquercetin on the quality of lipid milk base mixtures with different types of fibre, samples were stored in a thermostat at 20±2 °C for 16 days.

The effect of the antioxidant dihydroquercetin on the change in peroxide value of lipid milk base mixtures with plant ingredients during storage at (20±2) °C is presented in Figure 4.

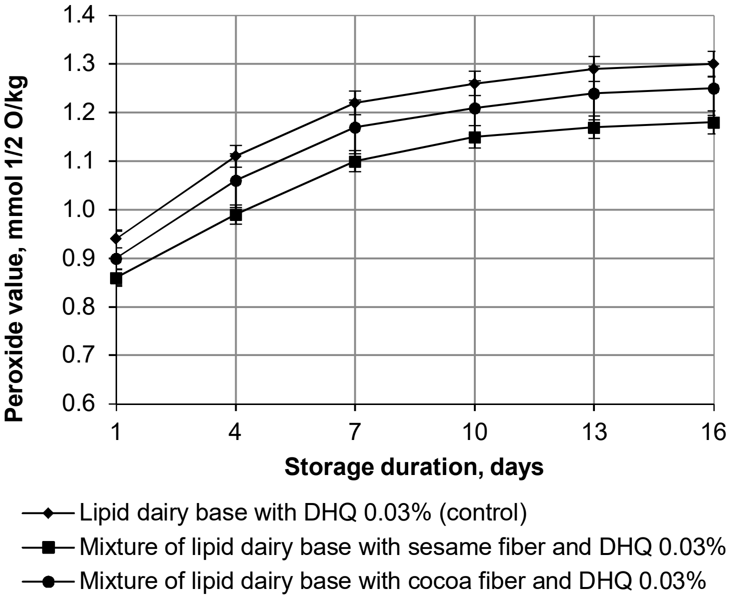

Figure 3. Influence of the antioxidant dihydroquercetin on peroxide value of lipid milk base mixtures with cocoa or sesame fibre during storage at (4±2) °C

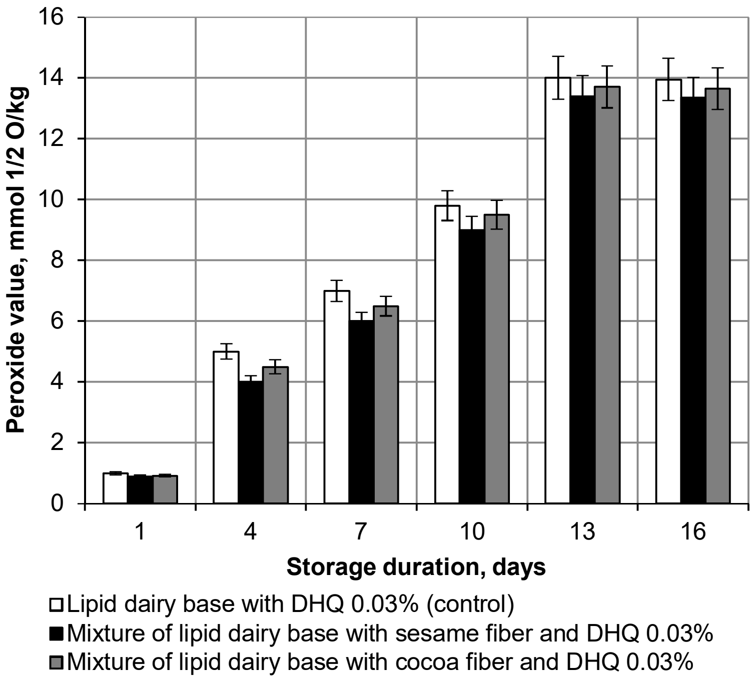

Figure 4. Influence of the antioxidant dihydroquercetin on the peroxide value of lipid milk base mixtures with plant ingredients during storage

The obtained data indicate that a significant increase in the peroxide value of mixtures of the lipid dairy base with plant ingredients and DHA, which occurs at a temperature of (20±2) °C, is consistent with the findings of other researchers. Lu et al. (2019) demonstrated that elevated temperatures significantly accelerate milk fat oxidation, while Yan et al. (2025) showed that substantial oxidation could occur even at moderate temperatures, as early as the 6th day of storage. Data on dry dairy products and pasteurized milk indicate a clear correlation between the accumulation of lipid oxidation products and the deterioration of sensory properties (Ajmal et al., 2018; Clarke et al., 2020). For example, after seven days of storage, the peroxide value of the control lipid dairy base with DHA increased sevenfold, whereas mixtures containing an antioxidant and plant ingredients increased slightly less, by 6.8 times for cocoa fibre and 6.7 times for sesame fibre. This effect is likely due to the phenolic compounds in cocoa and sesame fibres, which can neutralize free radicals and slow primary lipid oxidation (Tušek et al., 2024). Unlike cocoa polyphenols, whose antioxidant activity partially decreases during prolonged contact with oxygen and at elevated temperatures, sesame lignans are characterized by thermal stability and lipophilicity, which ensures their better integration into the fat phase and enhances the efficiency of peroxide formation inhibition (Oboulbiga et al., 2023). Modern studies confirm these mechanisms. In particular, experimental work has shown that sesamol and other lignans improve the oxidative stability of fatty matrices and reduce the formation of volatile oxidation products during heat treatment and storage (Cheng et al., 2024). These observations correspond to the results of studies by Morsy et al. (2022) and Oboulbiga et al. (2023), which additionally report high overall antioxidant activity of sesame by-products and the stability of these compounds in fat systems.

According to the findings by Tušek et al. (2024), the polyphenols contained in cocoa fibre demonstrate high antioxidant activity in aqueous and emulsion systems; however, their effectiveness in purely lipophilic environments may decrease under the influence of oxygen and elevated temperatures due to oxidative degradation and the loss of conjugated structures. At the same time, studies of cocoa fibre indicate their potential as a source of bioactives, but the effectiveness of these components in fatty matrices depends on the extraction method, the polarity of fractions, and application conditions (Braojos et al., 2024). Thus, the highest antioxidant activity during storage of mixtures of the lipid dairy base at a temperature of (20±2) °C is exhibited by the sample with the addition of sesame fibre and DHA. For all samples, on the 10th day of storage, the peroxide value was less than 10 mmol/kg ½ O, which is the maximum permissible level for ensuring storage duration according to the literature (Grek et al., 2021; Ustymenko et al., 2023). The studies showed that all antioxidants of various origins slowed down the oxidation processes in the lipid dairy base.

Effect of dihydroquercetin on the acid value of milk lipid-based mixtures with fiber during storage

During storage, in addition to oxidation products, the content of free fatty acids in the lipid dairy base also increased. The influence of the antioxidant dihydroquercetin on the acid value of mixtures of the lipid dairy base with different types of fibre during storage at (20±2) °C is shown in Figure 5, and at (4±2) °C in Figure 6.

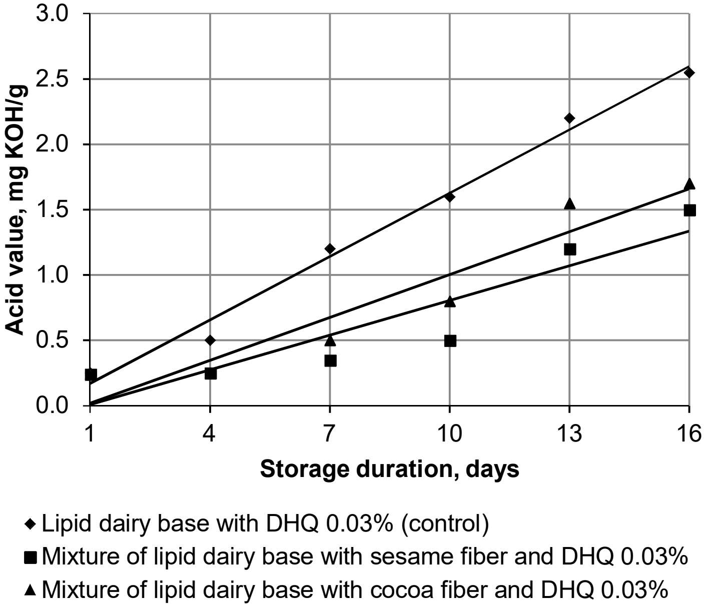

Figure 5. Influence of the antioxidant dihydroquercetin on the acid value of mixtures of the lipid dairy base with cocoa or sesame fibre during storage at (20±2) °C

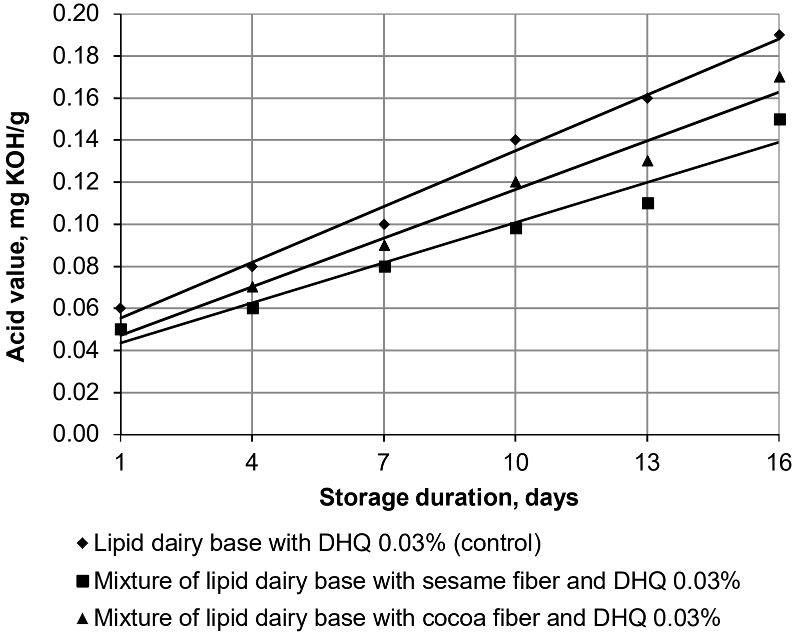

Figure 6. Influence of the antioxidant dihydroquercetin on the acid value of mixtures of the lipid dairy base with cocoa or sesame fibre during storage at (4±2) °C

According to the results presented in Figure 5, the change in the acid value of the lipid dairy base after 4 days of storage at (20±2) °C was insignificant. With an increase in the storage duration of the mixtures of the lipid dairy base, the acid value gradually increased, and the increase was most intensive in the control.

The increase in acid value on the 10th day of storage at (20±2) °C was noticeable only for the lipid dairy base with the antioxidant dihydroquercetin (6.4-fold), whereas for the mixture of the lipid dairy base with cocoa fibre and DHA the amount of free fatty acids increased 3.6-fold, and for the mixture with sesame fibre and DHA – 2.4-fold. After 13 days of storage, a significant increase in the acid value was recorded in the samples of the lipid dairy base with DHA – 8.8-fold, and in samples with added cocoa fibre and sesame fibre – 6.2-fold and 4.8-fold, respectively. As for the samples of mixtures of the lipid dairy base stored at (4±2) °C (Fig. 6), a similar trend toward increasing acid value is observed, comparable to mixtures stored at (20±2) °C.

Based on the results of the conducted studies, the developed mixtures of the lipid dairy base with cocoa or sesame fibre and the antioxidant dihydroquercetin maintain the stability of the fat phase (without significant oxidation) for no more than 13 days at a temperature of (4±2) °C. Thus, the antioxidant effectiveness of plant ingredients is determined by their ability to interact with peroxide radicals in the dairy lipid base. This interaction makes it possible to slow down or completely prevent further formation and accumulation of secondary oxidation products when dihydroquercetin is added.

Conclusions

The study demonstrates that cocoa and sesame fibre, alone or in combination with the antioxidant dihydroquercetin, effectively enhance the stability of lipid dairy base mixtures during storage. These plant fibres exhibit antioxidant and functional properties that reduce lipid oxidation and hydrolytic changes, while also contributing to the technological characteristics of the product. The combined use of fibre and dihydroquercetin produces a synergistic effect, improving oxidative stability and extending the shelf life of fat-containing dairy systems.

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