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DETERMINATION OF THE INFLUENCE OF HEMP OIL-BASED EMULSION SYSTEMS COMPOSITION ON THE OXIDATION PRODUCTS CONTENT DURING STORAGE

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The object of the study is the content of antioxidants and the induction period of accelerated oxidation under simulated conditions of the lipid component of the emulsion system. The way to solve the problem of developing compositions of oxidation-stable emulsion systems based on nutritionally valuable oils, in particular hemp oil, by adding natural physiologically active antioxidants is considered. The research is relevant in the context of finding effective storage methods and extending the shelf life of products using hemp oil. The feature of the work lies in determining the influence of the composition of emulsion systems based on hemp oil on chemical oxidation during storage. The content of stabilizers in the hemp oil emulsion system (lecithin – 0.8...1.0 %; xanthan gum – 0.0...0.1 %) is proposed, which is effective in the inhibition of oxidative spoilage. The content range of β-carotene (0.012 %) in model emulsion systems is outlined, the addition of which increases the induction period of accelerated lipid oxidation by 1.58...2.08 times. The peroxide value of the lipid component of the emulsion system during storage at different temperature conditions (0...15 °C) and during different storage periods (15...60 days) was studied.

The results of the study confirm the significant influence of the composition of emulsion systems on the chemical oxidation of the lipid component, which is important for ensuring the quality and stability of food, pharmaceutical and cosmetic products. An applied aspect of the obtained scientific result is the possibility of modeling the composition of emulsion systems based on valuable hemp oil depending on the ratio of polyfunctional antioxidants of the oil component

Keywords: hemp oil, emulsion system, lecithin, xanthan gum, β-carotene, oxidation products

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1. Introduction

Emulsion fat systems today play a key role in food production and occupy a significant share in a balanced diet. Such systems have not only high energy, but also biological value: they contain polyunsaturated fatty acids (PUFAs), fat-soluble vitamins and other biologically active substances necessary for the normal development of the body [1, 2].

A feature of liquid oils, in particular in emulsion systems, is their low resistance to spoilage, which leads to a decrease in nutritional value and even the acquisition of toxicity [3, 4]. Destructive microbiological processes also occur [5]. The shelf life of the specified products can be extended with the help of components that increase the resistance of the products to oxidative and microbiological spoilage. Various methods of improving the quality of fat systems and preventing their spoilage are used in the industry: optimized selection of ingredients, use of food additives, packaging in an inert atmosphere, and others. An important aspect is the creation of emulsion food products with a reasonable formulation not only of long shelf life, but also of increased nutritional value [5, 6].

When designing emulsion-based food systems, especially oil-water type, the greatest danger is the chain oxidation of PUFAs [6]. To extend the shelf life of emulsion systems, antioxidants are used, which can be divided into two groups. The first includes substances that, due to the presence of certain groups in the composition of molecules, for example, phenolic, reduce free radicals, thereby interrupting the chain reaction. The second group includes antioxidants that are not directly involved in the oxidation reaction, but are able to reduce the process intensity in various ways. In particular, this is stabilization against oxidative spoilage due to complex formation with catalytically active metal ions, or the ability to oxidize and regenerate already used antioxidants of the first group [7–9]. Antioxidants of the first group include both natural and synthetic substances. Among natural antioxidants, plant extracts are of special interest, particularly due to their preservative effect [6, 8, 10].

It is urgent to find ways to minimize the accumulation of oxidation products in emulsion systems based on oils with high nutritional value by substanting their composition. Therefore, studies aimed at analyzing the influence of the composition of lipid raw materials on the stability to chemical spoilage of emulsion systems are of great relevance and importance. The creation and research of model emulsion systems make it possible to study the influence of their composition on the stability of the lipid component to oxidation, allowing to determine the rational ratio of components to increase the shelf life and quality of food products. This is due to the need to expand the range of competitive emulsion products, in particular sauces, based on biologically valuable oils that meet consumer needs.

2. Literature review and problem statement

The study [11] analyzed the effectiveness of stabilization against oxidation of the emulsion lipid component by introducing natural extracts:

– sweetgrass (0.0003–0.0005 wt% in terms of dry matter);

– calamus rhizomes (0.0005–0.0034 wt% in terms of dry matter).

The drawback of this study is the insufficient effectiveness of these extracts in the specified concentration ranges. In addition, the presence of a foreign taste in the product is declared when adding sweetgrass or calamus rhizome extract in amounts above 0.0005 and 0.0034 wt%, respectively.

In [12], it is proposed to use aromatic oil extracts of mint, lemon balm, thyme, rosemary, coffee, orange or lemon essential oil, walnut leaf extract as oxidation inhibitors for oil emulsion systems. In addition, it is proposed to use some fruit extracts in [13] to stabilize oil systems against oxidation. In particular, pomegranate peel has been found to be an effective source of antioxidants for stabilizing the lipid component of emulsion systems. An unsolved issue of the mentioned studies is the uncertainty of the chemical composition of the obtained antioxidant extracts, which makes it difficult to identify the components with the highest activity. This issue is partially resolved in [14], where the total content of terpenes and terpenoids in a number of plant extracts used to stabilize fat-containing emulsions is determined. It has been proven that the most effective antioxidants in extracts are carnosol, rosmarinic, carnozoic acids, caffeic acid, rosmanol and rosmadial. But the issue related to the effectiveness of this antioxidant complex at elevated storage temperatures remains unresolved. Such studies were carried out in [15], where the effectiveness of a number of terpene-containing plant natural extracts in the stability of polyunsaturated oils during storage at elevated temperatures was noted. It was determined that stability to oxidative spoilage is not just a function of individual components, but can also consist of the cumulative effect of endogenous and exogenous antioxidants of oil compositions. Tocopherols, β-carotene, γ-oryzanol and phenolcarboxylic acids have been proven to be synergists. But it would be advisable to study the effect of the chemical composition of fatty acids of the lipid component on stability to oxidative spoilage. Such experiments were carried out in [6, 16, 17].

In particular, the work [16] determined that fat emulsions used for complete and partial parenteral nutrition have different effects on both technological parameters during storage and immunological functions in patients. This is primarily due to differences in the chemical composition of fat emulsions of different manufacturers, namely different qualitative and quantitative content of fatty acids. It is noted that oleic acid is the most resistant to peroxide oxidation of lipids and slightly affects the synthesis of inflammatory mediators, does not cause immunodepression or immunosuppression. In addition, the authors of [17] found that using oil extracts of natural antioxidants affects the quality preservation of peanut-flax blends of different ratios. These blends blends are used in dressings of increased nutritional value. It is shown that to assess the effect of plant extracts on the quality of the developed blends, it is appropriate to use the PUFA content as the main criterion for the effectiveness of the antioxidant complex. It was found that natural antioxidants contribute to the preservation of linoleic acid by 69.0–73.0 %, oleic acid by 73.5–78.9 %, and linolenic acid by up to 62 % of the initial content in peanut-flax blends. However, it should be taken into account that the same antioxidants may have different effectiveness depending on the type of oil that is part of the emulsion lipid component.

In [6], comprehensive studies of the composition and induction periods of accelerated oxidation of mixtures of hemp and corn oils, depending on their ratio, were carried out. The rational ratio of hemp and corn oils in the oil composition is 6:4, respectively (the content of α-linolenic fatty acid is 10.6 % of the total amount of fatty acids). The effect of the antioxidant complex (essential oils of coriander, basil and thyme) on the stability of the oil composition was determined. Hemp oil is a promising raw material for emulsion products, the special value of which lies in the high content of PUFA, reaching 84.9–86.3 % [18]. However, the high content of PUFA is a limitation for its use in a number of products. An unsolved issue of [6] is to determine the effect of various antioxidant complexes on the induction periods of accelerated oxidation of the oil composition under emulsified system conditions. Such antioxidants, in addition to their effectiveness, should not impair the organoleptic indicators of finished products.

In [19], model mayonnaise emulsions of direct type stabilized by lecithin at pH 7.0 were studied. It was evaluated, how sodium and potassium chlorides affect the quality characteristics of the emulsion system, including the oxidative stability of the lipid base. The results showed that these salts increase the particle size of the lipid phase, the negative charge of oil droplets and the amount of iron chelated by lecithin. In addition, the presence of food salt and its substitute increased the rate of oxidative spoilage of the lecithin-stabilized emulsion system. However, it is necessary to take into account the effect of other complex food additives on the oxidative stability of the specified emulsion product, in particular, a dye with antioxidant properties – β-carotene.

The study [20] determined the effect of β-carotene and soy protein in the composition of low-calorie mayonnaise sauce on the physical and chemical parameters of the product. It was found that the presence of β-carotene in the emulsion system contributed to a change in the spatial structure of soy protein molecules, which positively affected the emulsion stability. The interaction between protein molecules and β-carotene has been proven to be supported by hydrophobic interactions. The features of β-carotene interaction with other components of emulsion products, in particular consistency stabilizers, remain an unresolved issue.

There is a need to expand scientific data on the development of compositions of oxidation-stable emulsion systems based on nutritionally valuable oils, in particular, hemp oil by adding natural physiologically active antioxidants. In view of this, a study on identifying the influence of the content of fat-soluble antioxidants in the lipid component on the induction period of accelerated oxidation of the hemp oil emulsion system is considered advisable. It is of interest to study the effect of fat-soluble antioxidants of the lipid component of the emulsion system, which, in addition to biological value, take part in the formation of quality indicators of the finished product, in particular, the consistency stabilizer lecithin and the dye β-carotene. This will expand the range of emulsion products with physiologically active components: PUFA of the ω-3 group and provitamin A.

3. The aim and objectives of the study

The aim of the study is to determine the effect of the composition of hemp oil emulsion systems on the content of oxidation products during storage. The obtained results will make it possible to expand the range of emulsion products with increased biological and nutritional value.

To achieve the aim, the following objectives were accomplished:

– to determine the dependence of the oxidative stability of the emulsion system containing hemp oil on the content of lecithin and xanthan gum during accelerated oxidation;

– to examine the inhibition of oxidative spoilage of the emulsion system of the developed composition using β-carotene;

– to investigate the resistance to oxidative spoilage during storage of the emulsion system of the developed composition containing hemp oil.

4. Materials and methods

4. 1. Object and hypothesis of the study

The object of the study is the composition of an emulsion system of increased nutritional and biological value based on hemp oil with the addition of β-carotene, which is stable to oxidation.

The main hypotheses of the study are:

– the possibility of increasing the biological and nutritional value of the emulsion system due to such components as hemp oil (source of ω-3 PUFA) and β-carotene (provitamin A, antioxidant);

– the possibility of extending the shelf life of the emulsion system containing ω-3 PUFA by using natural β-carotene. This compound can donate electrons or intercept the energy of singlet oxygen, thereby reducing its reactivity and ability to damage lipids.

The study assumes that the induction period of accelerated oxidation of samples of the lipid component of the emulsion system is proportional to their induction period of oxidation under the recommended storage conditions (no light access from 0 °C to +10 °C).

The following simplifications were adopted in the study:

– the effect of other antioxidants, in particular tocopherols present in oils, on the oxidative spoilage of the lipid component of the emulsion system is not taken into account;

– hemp and corn oil samples, as well as β-carotene oil solution from different manufacturers have almost similar chemical composition, physicochemical parameters and stability to oxidative spoilage.

4. 2. Materials used in the experiment

The following materials were used during the research:

– refined hemp oil (produced in Ukraine), according to CAS 89958-21-4;

– refined corn oil (produced in Ukraine), according to CAS 8001-30-7;

– 0.2 % β-carotene oil solution (manufactured in China), according to CAS 7235-40-7;

– liquid soy lecithin (produced in Ukraine), according to CAS 8002-43-5;

– xanthan gum (manufactured in China), according to CAS 11138-66-2;

– citric acid (produced in Ukraine), according to CAS 77-92-9;

– distilled water (produced in Ukraine), according to CAS 7732-18-5.

4. 3. Methods of studying consumer properties of lipid raw materials for emulsion systems

The moisture and volatile matter content is determined by the gravimetric method according to DSTU 4603. The peroxide value of the lipid raw material is determined by the titrimetric method according to DSTU ISO 3960, respectively.

4. 4. Method of determining the induction period of accelerated oxidation of the lipid component of emulsion systems

The induction period of accelerated oxidation of the lipid component of emulsion systems was determined by the accelerated method of “reactive oxygen” according to DSTU ISO 6886. The principle of the method is to keep samples of the studied material at a constant elevated temperature (80±2 °C) and free access of oxygen, mixing and periodically determining the peroxide value of lipid samples extracted from the samples. The lipid peroxide value characterizes the degree of accumulation of the primary oxidation products. The induction period is defined graphically as the period of time after which there was a significant increase in the peroxide value, i.e. the concentration of the primary oxidation products (peroxides and hydroperoxides).

4. 5. Method of obtaining model samples of emulsion systems

Model samples of emulsion systems were obtained as follows. Prepared lipid raw materials (oils, lecithin, β-carotene oil solution) are mixed to create a blend, heating to 35 °C is applied. Citric acid (concentration 10 %) and xanthan gum are dissolved in the prepared water. Then lipid raw materials are gradually added to the aqueous solution with careful stirring, the emulsion system undergoes homogenization (speed not less than 1,000 rpm) for 5 minutes.

4. 6. Methods of determining the physical and chemical parameters of emulsion systems

The physico-chemical parameters of emulsion systems are determined according to DSTU 4487. The peroxide value of the lipid fraction of the emulsion system is determined according to DSTU ISO 3960. The lipid fraction of the emulsion system is extracted by the extraction method.

4. 7. Research planning and statistical processing of results

The experiments were performed three times. To determine the dependence of the induction periods of accelerated oxidation of model samples of the emulsion system with different emulsion stabilizers on the β-carotene content, a single-factor regression method with plotting using the Microsoft Excel software package (USA) was chosen. Statistical models of dependencies are defined by approximating the experimental results by constructing a trend line. The quality of the equations of dependencies (1) and (2) and the completeness of the influence of β-carotene content on the induction period of accelerated oxidation of the lipid component of the emulsion system were evaluated by approximation reliability values equal to 0.964 and 0.980, respectively. This allows us to conclude that variations in β-carotene content have a high effect on variations in the induction period of accelerated oxidation of the lipid component of the emulsion system.

To process data on the dependence of the oxidation induction period of the lipid component of the emulsion system on storage time and temperature, mathematical methods were applied using the Stat Soft Statistica v 6.0 software package (USA). The significance of individual coefficients of the regression equation (3) was determined using the Student's test (t) by testing the hypothesis that the corresponding parameter of the equation is equal to zero. The calculated absolute value of the Student's test t (8) when evaluating individual regression coefficients was compared with its critical table value $t_{\text{table}}(8)=2.31$ at the significance level $p=0.05$ and the number of degrees of freedom for multiple regression $df=8$. The data and conclusions on determining the significance of the coefficients of the regression equation (3) are given in Table 1.

Table 1

Conclusions on determining the significance of the coefficients of the regression equation (3)

Coefficient of the regression equation at	Coefficient value in natural quantities	t (8)	t_{table} (8)	Estimated probability of null hypothesis for the coefficient of the regression equation (p-level)	Conclusion on the significance of the coefficient
Intercept	0.965	4.21753	2.31	0.000381	Significant
T	– 0.2895	7.49224		0.001465	Significant
τ	0.0065	4.51541		0.008063	Significant

To assess the quality of the regression equation (3) and the completeness of the influence of the selected factors, the coefficient of determination R^2 was defined. The obtained value of $R^2=0.94$ allows us to conclude that there is a very significant effect (greater than 94 %) of storage temperature and time variations on variations in the peroxide value of the lipid component of the emulsion system with β-carotene. To determine the significance of the regression model, Fisher's test (F) was calculated, on the assumption that the equation is statistically insignificant ($R^2=0$; null hypothesis). The calculated Fisher's test value was $F(2.8)=16.265$ and was greater than its critical table value $F_{\text{table}}(2.8)=4.46$ at the significance level $p=0.05$ and the number of degrees of freedom $df_1=2$ and $df_2=8$. This result allows us to reject the null hypothesis and, with a probability of 92 %, recognize the value of the coefficient of determination $R^2=0.94$ as significant, and the model as significant.

5. Results of determining the influence of the composition of hemp oil-based emulsion systems on the content of oxidation products

5. 1. Determining the dependence of the oxidative stability of the emulsion system containing hemp oil on the content of lecithin and xanthan gum

Based on the results of the work [6], which substantiates the oil composition with a physiologically significant content of PUFAs of the ω–3 group, model samples of the emulsion system of the composition given in Table 1 were produced.

Table 1

Composition of model samples of the emulsion system

Name of the component	Content, %
Oil composition consisting of:	70.0
Hemp oil	42.0
Corn oil	28.0
Citric acid	2.0
Distilled water	27.0
Lecithin	0.0...1.0
Xanthan gum	0.0...0.5

The effect of the ratio of the effective content of emulsion system stabilizers (lecithin and xanthan gum) on the induction period of accelerated oxidation of its lipid component was determined. The diagram of the resulting dependence is shown in Fig. 1.

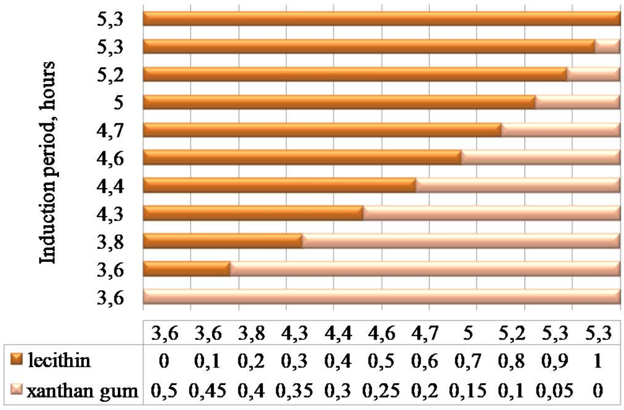

Fig. 1. Dependence of the induction period of accelerated oxidation of model samples of the emulsion system on the content of emulsion stabilizers

The lecithin content in the emulsion system was varied in the range of 0.0...1.0 % with a step of 0.1 %. The xanthan gum content is in the range of 0.0...0.5% with a step of 0.05 %. It should be noted that the emulsion stability in the samples was about 100.0 %. The obtained values of the induction period of accelerated oxidation of the oil composition were within 3.6...5.3 hours.

5. 2. Study of the inhibition of oxidative spoilage of the emulsion system of the developed composition with the help of β-carotene

The effect of 0.2 % β-carotene oil solution on the induction period of accelerated oxidation of the model sample of the composition emulsion system was studied (emulsion stabilizers: lecithin – 0.8 %, xanthan gum – 0.1 %). As a control sample, a similar model sample of the emulsion system was used, where the emulsion stabilizer is xanthan gum – 0.5 %. Graphical displays of the obtained dependencies are shown in Fig. 2.

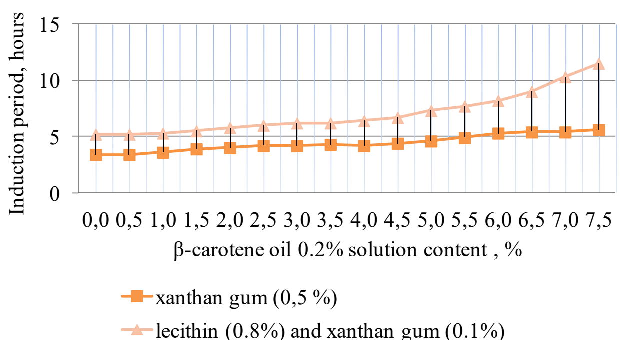

Fig. 2. Dependence of induction periods of accelerated oxidation of model samples of the emulsion system on the β-carotene content

Approximate dependences of the value of the induction period of accelerated oxidation of model samples of the emulsion system on the content of 0.2 % β-carotene oil solution ($c_{β\text{-}c}$, %) are presented by the equations:

– model emulsion system stabilized with lecithin (0.8 %) and xanthan gum (0.1 %) – $PI_{l/c}$ ($c_{β\text{-}c}$) (1);

– model emulsion system stabilized by xanthan gum (0.5 %) – PI_c ($c_{β\text{-}c}$) (2):

$$p_{l/c}(c_{\beta-c}) = 0.0141c_{\beta-c}^2 + 0.0278c_{\beta-c} + 5.1854; \quad (1)$$

$$P_c(c_{\beta-c}) = 0.0012c_{\beta-c}^2 + 0.1321c_{\beta-c} + 3.3375. \quad (2)$$

It should be noted that the given dependences make it possible to adequately calculate the induction period of accelerated oxidation of the emulsion system, which is directly proportional to the storage period, in the intervals of the content of 0.2 % β-carotene oil solution of 0.0...7.5 %.

5. 3. Study of resistance to oxidative spoilage during storage of the emulsion system of the developed composition

To determine the influence of such parameters as storage temperature and storage time on the shelf life of the emulsion system stabilized by β-carotene, the content of the primary oxidation products formed during the oxidation process was investigated. The content of the primary oxidation products of the lipid component (peroxides and hydroperoxides) is characterized by the peroxide value (PV). Equation (3) shows the approximate dependence of the PV value of the lipid component of the emulsion system with β-carotene ($PI\,(T, τ)$) on the storage temperature (T) and storage time (τ):

$$PI\,(T, \tau) = 0.965 - 0.2895 \cdot T + 0.0065 \cdot \tau + 0.0425 \cdot T^2 + 0.0055 \cdot T \cdot \tau + 0.0004 \cdot \tau^2. \quad (3)$$

The surface of the resulting dependence (3) is shown in Fig. 3.

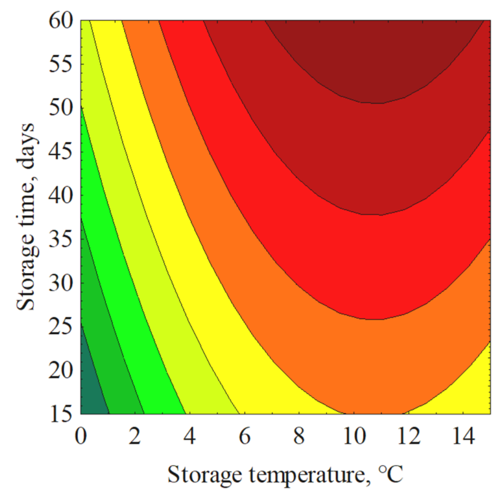

Fig. 3. Dependence of the peroxide value of the lipid component of the emulsion system with β-carotene on storage temperature and time

It should be noted that the calculated dependence (3) adequately describes the peroxide value in the storage range at temperatures of 0...15 °C and during storage periods of 15...60 days. The pH value of the emulsion system stabilized by lecithin (0.8 %) and xanthan gum (0.1 %) with β-carotene (0.012 %) varies in the range of 1.1...13.4 mmol ½O/kg.

6. Discussion of the results of determining the influence of the composition of hemp oil-based emulsion systems on the content of oxidation products

The effect of the content of fat-soluble antioxidants in the lipid component (lecithin and β-carotene) on the chemical shelf life (oxidative stability) of the hemp oil emulsion system was determined (Table 1). Peroxide value is a key indicator of lipid component oxidation when investigating vegetable oil emulsion systems due to its sensitivity to the initial oxidation steps. Determination of the peroxide value reveals even minor changes in the composition of emulsion systems, reflecting their resistance to oxidation. The dependence of the induction period of accelerated oxidation of the emulsion system containing hemp oil on the content and ratio of consistency stabilizers – lecithin and xanthan gum (Fig. 1) is determined graphically. Based on the results of experimental data, a rational content of emulsion stabilizers in the emulsion system is proposed, namely:

– lecithin – 0.8...1.0 %;

– xanthan gum – 0.0...0.1 %.

In these ranges, the induction period of accelerated oxidation is 5.2...5.3 hours, i.e. 44.4...47.2 % more than that in the emulsion system stabilized by xanthan gum. The obtained data suggesting the antioxidant effect of lecithin can be explained as follows. Lecithin has the ability to form stable micelles in emulsion systems, where hydrophobic fragments of lecithin molecules surround lipid droplets to form a protective layer. This helps to slow down the chemical destruction of lipids, reducing their interaction with oxygen. In addition, lecithin is an electron acceptor in free radical oxidation reactions. In contrast to [6, 17], the obtained results take into account the ratio between the specified stabilizers and their effect on the induction period of accelerated oxidation of model samples of the emulsion system (Fig. 1). This is a key aspect in ensuring the stability of emulsion systems. This approach provides a rational balance between stabilizing the emulsion and ensuring the chemical stability of the lipid component, which is important for fat-containing emulsion products.

The effect of inhibition of the processes of chemical destruction of the lipid component of model samples of the emulsion system by adding β-carotene in the form of oil solution was investigated (Fig. 2, equations (1), (2)). A feature of the study was the use of model samples of the emulsion system stabilized by various compounds (lecithin+xanthan gum – equation (1); xanthan gum – equation (2)). From the analysis of the experimental results, the effective range of the content of 0.2 % β-carotene oil solution in model emulsion systems was outlined, the addition of which increases the induction period of accelerated oxidation by 1.58...2.08 times (equations (1), (2)). Moreover, the non-additive mutual influence of β-carotene and lecithin during the inhibition of oxidative processes in the model sample of the emulsion system was proved (Fig. 2, equation (1)). The composition of the model emulsion system containing the stabilizers lecithin (0.8 %) and xanthan gum (0.1 %) and 0.2 % β-carotene oil solution (6 %, in terms of β-carotene – 0.012 %) is proposed. The non-additive effect of β-carotene and lecithin on the inhibition of oxidative processes in the composition of the emulsion system can be explained by the peculiarities of their interaction in the emulsion system. Peculiarities of the distribution of lecithin and β-carotene molecules, changes in the microstructure of the emulsion system, which may affect the inhibition efficiency of oxidative processes, are likely. In contrast to [11–13], the research results substantiate the effective concentrations of β-carotene and lecithin antioxidants in model emulsion systems in pure form, not extracts, which contributes to a non-additive increase in the oxidation induction period. This opens up new opportunities for optimizing emulsion composition in order to increase oxidation resistance. Dependencies (1) and (2) allow adequate calculation of the induction period of accelerated oxidation of the emulsion system in the specified ranges. A similar calculation possibility is substantiated in [7].

Resistance to oxidative spoilage during storage of the emulsion system of the developed composition was determined. The proposed graphical (Fig. 3) and statistical dependencies (3) can be used to predict the peroxide value, which is an important indicator of chemical stability, and, accordingly, the shelf life of the specified emulsion system. The linear terms (T, τ) have a significant effect on the peroxide value of the lipid component of the emulsion system. In particular, the storage temperature has the greatest negative effect on the peroxide value. The quadratic terms (T^2, τ^2) indicate the non-linear influence of these factors. In particular, the quadratic term of temperature (T^2) has a positive influence (0.0425), indicating a minimum or a maximum depending on other conditions. The interaction term ($T{\cdot}\tau$) has a positive effect, but is smaller (0.0055), indicating a relationship between storage temperature and time. Unlike other works, in particular [6], the calculated dependence (3) describes the change in the peroxide value depending on the complex of storage conditions: under different temperature conditions and storage periods. Thus, the obtained data allow to effectively control and predict the oxidation degree of the hemp oil emulsion system, which is important for ensuring product quality and safety during storage.

The results of the conducted studies (dependencies (1)–(3)) make it possible to substantiate the development of new emulsion systems based on biologically valuable hemp oil with improved resistance to oxidative spoilage. They can be used to expand the range of foods, cosmetics or pharmaceuticals that retain high quality for a long time. Also, the obtained results (Fig. 1, equations (1), (2) can serve as a basis for improving storage and transportation technologies of lipid-containing emulsions with PUFA. This will help increase their stability and ensure the preservation of physiological properties.

The results of studies on determining the influence of the composition of hemp oil emulsion systems on chemical oxidation during storage can be applied in various areas. First of all, these data are important for industrial food manufacturers, as they allow developing new formulations of biologically valuable emulsion products with a longer shelf life. In addition, the research results can be useful for the pharmaceutical and cosmetic industries, where ensuring the stability of medicines and cosmetics during storage is an extremely important aspect.

Restrictions on the use of the research results, in particular dependencies (1)–(3), may arise for a number of reasons. The research results are limited by the chosen methodology and experimental conditions, which may complicate their applicability to other conditions. In addition, although the study provides very important information regarding the influence of the chemical composition of the model emulsion system on chemical oxidation, additional research may be necessary to fully understand the mechanisms of this process and develop practical applications. It is also necessary to consider factors that may affect the stability of the results, such as conditions for the use of emulsion products, interaction with other components, and potential additional effects in real production conditions.

The disadvantage of the conducted studies is the lack of data on the microbiological stability of the emulsion system during the specified period of time. It should be noted that the shelf life of emulsion products containing preservatives in the amount justified by regulatory requirements is directly proportional to the chemical stability of the oil component.

Promising areas of the conducted research are to expand the research area to other types of emulsion systems or lipid matrices to expand the versatility of conclusions and recommendations to manufacturers. It is also promising to study the interaction of the components of the developed emulsion system with other additives or ingredients to optimize their consumer properties.

7. Conclusions

1. The dependence of the oxidative stability of the emulsion system containing hemp oil on the content of lecithin and xanthan gum during accelerated oxidation was determined. A rational content of stabilizers in the emulsion system based on hemp oil is proposed (lecithin – 0.8...1.0 %; xanthan gum – 0.0...0.1 %). The induction period of accelerated oxidation under the proposed conditions increases by 44.4...47.2 % from the same in the emulsion system stabilized by xanthan gum alone.

2. Features of inhibition of oxidative spoilage of the emulsion system of the developed composition with the help of β-carotene were studied. It was found that β-carotene effectively interacts with free radicals formed at the initial stages of oxidation, preventing their further reaction with lipids. This leads to a decrease in the formation of primary and secondary oxidation products, which affect the taste, smell and quality of the product. The non-additive mutual influence of β-carotene and lecithin during the inhibition of oxidative processes in the model sample of the emulsion system was proved. The content range of β-carotene (0.012 %) in model emulsion systems is outlined, the addition of which increases the induction period of accelerated lipid oxidation by 1.58...2.08 times, depending on the type of stabilization complex.

3. The peroxide value of the lipid component of the emulsion system during storage at different temperature conditions (0...15 °C) and during different storage periods (15...60 days) was studied. A two-factor quadratic approximation dependence is proposed, which relates such factors as storage temperature and time to the peroxide value (content of primary oxidation products) of the lipid component of the emulsion system. Optimal values of the storage temperature and time of the emulsion system are determined by minimizing the peroxide value, that is, the minimum storage temperature and time. The most significant factor of the dependence is the storage temperature, which is confirmed by the largest coefficient in the equation. The obtained approximation dependence is recommended to be used for monitoring and forecasting the dynamics of accumulation of primary oxidation products in the lipid component of the hemp oil emulsion system during storage.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, whether financial, personal, authorship, or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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