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PREDICTING THE SHELF LIFE OF SUNFLOWER MEAL USING KINETIC MODELS

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Abstract. The issue of determining the shelf life of sunflower meal using a kinetic approach has been considered. Sunflower meal is a byproduct of sunflower oil production and is actively used in agriculture as a high-calorie component of compound feeds for poultry, pigs, and cattle. The main value of meal lies in its high protein content (up to 44%), fiber, vitamins B and E, potassium, phosphorus, and other important minerals and organic substances. However, it contains up to 2% oil, which over time is prone to oxidation, potentially negatively impacting the product's quality and safety. The study proposes a method for predicting the oxidative stability of sunflower meal during long-term storage using the Arrhenius model, which describes the dependence of the reaction rate on temperature. The peroxide value was used to describe the kinetics of lipid oxidation in the meal. It was found that the oxidation reaction demonstrates clear zero-order kinetics, and the activation energy for the formation of primary oxidation products is 71.875 kJ/mol. A kinetic equation for the oil oxidation reaction in meal was developed, allowing for the calculation of the reaction rate constant at different temperatures. Calculations of the reaction rate constants at temperatures of 293, 298, and 303 K showed that oil oxidation in meal depends on temperature, with a temperature acceleration coefficient of the reaction equal to 2.65. The predicted shelf life of the meal at a temperature of 298 K was 13.1 months. The accuracy of the prediction was confirmed by measuring the peroxide value of the meal stored for 12 months at temperature of 293–303 K and a relative humidity of 35–45%. The proposed method allows, in a short period, to provide recommendations regarding storage periods to ensure high quality and safety of the product, considering different temperature conditions.

Key words: sunflower meal, oxidation, peroxide value, rate constant, kinetics, shelf life.

Introduction. Formulation of the problem

The primary product derived from sunflower seeds is oil. Sunflower cake or meal are secondary products of sunflower oil production. The type of secondary product depends on the method used to extract the oil. Mechanical pressing of seeds results in cake, whereas chemical extraction using reagents such as hexane, petroleum ether, or naphtha produces meal. Oil extraction is the most common method because it yields a secondary product with a lower oil content compared to pressing (2% versus 10%). The meal is produced either in granular or loose form, depending on the final processing type. Sunflower kernel meal (without hulls) can be used as a food protein supplement in bakery products, meat and dairy products, as well as in mayonnaise, since it does not contain anti-nutritional substances. The fat content of the meal is around 1.5%, while the protein content varies between 36% and 44%, with sunflower seed protein being more easily digestible for the human body compared to animal proteins [1-4]. Sunflower meal contains higher amounts of sodium and calcium compared to cereal grains. Despite its high biological value and digestibility, only 15% of these secondary sunflower seed processing products are utilized by the food industry [1]. Typically, sunflower seed processing by-products, which are the cheapest source of protein in our country, are used as protein supplements in the diets of livestock and poultry. The use of such feed contributes to increased profitability and improved quality of livestock products. However, despite these advantages, meal and cake remain underutilized in the food industry.

Since 2017, Ukraine has seen a significant increase in the share of sunflower meal exports. This became possible due to the active construction of extraction plants and transshipment terminals in the early 2000s. After the introduction of a 23% export duty on sunflower seeds in 1999, exporting seeds became economically unviable. Until 1999, Ukraine actively exported sunflower seeds, while the export of sunflower oil and the secondary product of oil production – meal – occurred irregularly [5]. During the wartime 2022/23 marketing year, Ukraine exported just over 4 million tons of sunflower meal, generating $895.3 million (at $213.4 per ton). This represents a 24% increase compared to the previous season, but it remains one of the lowest figures in the last seven seasons. Export volumes increased across all major directions, yet China and the European Union remained the primary importers of Ukrainian meal, with shares of 42% and 31%, respectively (45% and 31% in the 2021/22 season). Notably, exports to China grew by about 16%, while those to EU countries increased by nearly 70%. Significant growth in Ukrainian sunflower meal exports was also recorded in Morocco (+77%), Egypt (+94%), and Israel (2.7 times). It is important to note that the Chinese market is highly demanding. According to official standards, sunflower meal exported to China must meet the country's feed safety and hygiene requirements. In Ukraine, all types of sunflower meal are produced in accordance with DSTU 4638:2006 “Sunflower meal. Technical specifications,” which stipulates a storage period of up to 3 months. According to the Law of Ukraine “On Feed Safety and Quality,” the minimum shelf life of feed (feed material) is the period during which, under proper storage conditions, the market operator responsible for labeling guarantees the preservation of the declared properties.

Sunflower seeds and their by-product, meal, are complex and active systems in which microbiological, enzymatic, and physicochemical reactions simultaneously occur, limiting the shelf life of this product [6]. Lipids are considered the key factor influencing the shelf life of the meal [7]. During storage, hydrolytic and oxidative processes in the oil contained in sunflower meal are activated, with its triglycerides comprising linoleic and monounsaturated acyl groups [8]. These processes not only reduce the nutritional value of the product but can also negatively impact its safety and hygienic characteristics. Therefore, to assess the biochemical changes that occur in the meal during storage and affect its quality, not only indicators such as crude protein, crude fiber, moisture content, residual pesticides, and pest infestation are used, but also acid and peroxide values of the meal's oil [9,10].

Today, thanks to the introduction of new sunflower varieties, the use of efficient modern technologies and oil extraction equipment, as well as the implementation of optimal storage conditions for meal, the shelf life during which the physicochemical properties of the meal meet the regulatory requirements has significantly increased. This means that the meal can remain suitable for use for a longer period.

Based on the above, determining the stability of lipids and, consequently, establishing the minimum shelf life of meals is a relevant and important task.

Analysis of recent research and publications

There are two methods for conducting shelf life studies of food products: direct and indirect testing. The direct method involves determining the shelf life in real-time. This method includes storing the product under specific conditions for a period that exceeds the expected shelf life, with periodic testing until spoilage occurs. The indirect method allows for predicting the shelf life without prolonged storage, making it more appropriate for products with long shelf lives. In this method, the shelf life is calculated based on information obtained by deliberately accelerating the spoilage process, for example, by increasing the storage temperature [6, 7].

There are not many studies focused on determining the shelf life of meals or cakes. The work [8] is dedicated to the quantitative assessment of nutrient content and oxidative stability of flaxseed cake over a 6-month storage period at room temperature in two different types of packaging: paper and polypropylene bags. Flaxseed cake is classified as a product that quickly undergoes oxidation due to the oil in flaxseeds, which is rich in alpha-linolenic acid. The researchers did not find significant differences in the quality and safety indicators of the cake when stored in paper or plastic bags for 6 months. Similar studies related to determining the shelf life of cakes, particularly flaxseed cake, are extremely important. However, it should be noted that flax is considered a niche crop, and therefore flaxseed cake is not as widely used as, for example, soybean or sunflower meal.

The study [11] characterizes pecan nut cake, a secondary product of pecan oil extraction, which tends to undergo rapid oxidation and quality degradation during storage, as pecan seeds are a rich source of lipids primarily composed of mono- and polyunsaturated fatty acids (over 70% of total lipids). The research examined the effect of packaging conditions on the shelf life of the cake. Pecan cake samples were packaged under vacuum or in normal atmospheric conditions and stored in a dark place at temperatures of +10 or +20 ºC for 12 months. Vacuum packaging in low-permeability film at temperatures of +10 or +20 ºC helped preserve the oxidative stability of pecan cake after one year of storage. Therefore, the authors of the study concluded that the correct combination of packaging and temperature contributes to maintaining the relevant quality characteristics of the food product.

In the study [12], researchers investigated the storage of raw and extruded (at temperatures of +100–+140 ºC) flaxseed cakes for 90 days at room temperature (+20–+25 ºC). In the extruded cake, the content of α-linolenic acid and the peroxide values of the lipids did not significantly change during storage for 60 days. However, by the 90th day, the extruded samples no longer met quality and safety requirements. This research demonstrated that the extrusion of flaxseed cake at temperatures of +100–+140 ºC, when stored for 60 days, does not affect its oxidative stability. Consequently, the specified product can be recommended for use as an additive or ingredient in the production of various health-beneficial products.

In the study [13], the effect of extrusion at different temperatures on the oxidative stability of lipids in flour made from untreated oat grains was examined over a 15-week storage period. The research established that lipids in oat grains can be stabilized through extrusion at temperatures of +70–+110ºC, while increasing the temperature to +130 ºC promoted lipid oxidation.

In the study [14], the oxidative stability of lipids in quinoa meal was investigated. The ground quinoa was subjected to accelerated aging for 30 days at temperatures of +25, +35, +45, and +55 °C. Samples were taken every three days after each temperature treatment. To assess lipid oxidation in quinoa, acid and peroxide values were used. The results indicated that the lipids in quinoa remained stable throughout the study period, largely due to the high content of the natural antioxidant vitamin E in quinoa.

Similar studies related to determining the shelf life of meal products, particularly flaxseed (both raw and extruded), oat, quinoa, or pecan meal, are extremely important for understanding the processes that occur during the storage of these products, with the aim of their elimination. However, it should be noted that flax belongs to niche crops, and pecans only grow in North America, the southeastern United States, Asia, the Caucasus, and Crimea. Therefore, the meals discussed in works [8, 11-14] cannot be considered as widespread as, for example, soybean or sunflower meal.

In work [7], a kinetic approach was applied to predict the shelf life of walnuts, which are highly sensitive to oxidation due to their high levels of polyunsaturated fatty acids (62–75% of the total lipid content), using elevated temperatures of +62, +72, and +82 ºC. The oxidation of lipids in walnuts was assessed by the peroxide value. Researchers established an energy range of 74.01–79.57 kJ mol^{-1} K^{-1} necessary for the formation of primary oxidation products. The changes in the reaction followed first-order kinetics. It was determined that the formation of hydroperoxides in walnut kernels is a temperature-dependent reaction with a Q10 (the ratio of the rate constants of the reaction at a temperature difference of 10 °C) equal to 2.1. At the same time, to verify the accelerated approach to assessing shelf life, walnut kernels were stored for 12 months at temperatures of +20…+30 ºC and relative humidity of 35–45%. Although this work does not focus on meals or cake, it is interesting because it compares the results of studies on oxidative stability for predicting the storage periods of high-fat products using an indirect method – by applying elevated temperatures – and a direct method – over 12 months.

The meal obtained through extraction contains a small amount of lipids that are prone to oxidation under the influence of external factors. This can lead to a deterioration in their quality and safety, especially during prolonged storage. Based on previous studies dedicated to the storage of oilseed meals, cereal crops, and nuts, it has been established that two methods can be used to determine the shelf life: direct and indirect. At the same time, there is insufficient research in the literature focused on predicting the shelf life of sunflower meals. Therefore, conducting research to develop an effective tool for predicting the shelf life of sunflower meals, in order to avoid errors in determining their compliance with safety and quality parameters, is relevant.

The purpose of this work is to:
– investigate the oxidative stability of sunflower seed oil under different temperatures over a specified period of time;
– evaluate the oxidative stability of sunflower meal after 12 months of storage;
– determine the kinetic parameters of the oxidation reaction of sunflower seed oil;
– develop an equation that describes the kinetics of sunflower meal oil oxidation;
– predict the shelf life of sunflower meal and compare the obtained results with the actual shelf life of the experimental sample of meal that was stored for 12 months.

Research materials and methods

For the research, the following materials were used: high-protein toasted granulated sunflower meal in accordance with DSTU 4638:2006 "Sunflower Meal. Technical Specifications".

Table 1 – Initial indicators of high-protein toasted granulated sunflower meal

Indicator Name	Control Method	Standard	Characteristics of Indicators
Appearance	DSTU 4638:2006	Cylindrical-shaped granules	Cylindrical-shaped granules
Color		Gray of various shades	Gray with a brownish tint
Smell		Characteristic of sunflower meal without foreign odors (mustiness, mold, rancidity)	Characteristic of sunflower meal without foreign odors (mustiness, mold, rancidity)
Diameter of granules, mm		6.0–20.0	8.0
Length of one granule, mm		10.0–26.0	20.0
Mass fraction of moisture and volatile substances, %	DSTU 7621:2014	9–11	10.82
Mass fraction of ash not soluble in 10% hydrochloric acid, calculated on a completely dry basis, % not more than	DSTU 9174:2022	1.0	0.10
Mass fraction of fat and extractive substances in absolutely dry matter, %, not more than	DSTU 7458:2013	1.5	1.10
Content of foreign impurities (pebbles, glass, soil)	DSTU 4638:2006	Not allowed	Not detected
Mass fraction of metal contaminants, %, not more than: - particles up to 2 mm in size, inclusive	DSTU 4600:2006	0.01	Not detected
- particles larger than 2 mm with sharp edges		Not allowed	Not detected
Presence of pests or signs of contamination	DSTU 9175:2022	Not allowed	Not detected
Mass fraction of residual solvent (naphtha), %, no more than	SOU 15.4-37-214	0.08	0.002
Crude protein in absolutely dry matter, %, no less than	DSTU 7169:2010	39.0	40.50
Mass fraction of crude fiber expressed on absolutely dry matter, %, no more than	DSTU 8844:2019	23.0	21.07
Mass fraction of granules that passed through a 2 mm sieve	DSTU 4638:2006	Not more than 5.0	2.0
Acid number of fat, mg *KOH*/g, no more than	DSTU 8048:2015	30.0	4.0
Peroxide number of fat, % iodine, no more than	DSTU 8659:2016	0.4	0.03

There is no universal mathematical theory that can be used to model all quality changes in food products, including meal. This is due to the fact that product quality can vary based on many physical and chemical indicators. However, it is possible to identify a key spoilage marker that can be easily measured and monitored for its changes over time. The peroxide value has been used to describe the kinetics of lipid oxidation as a function of temperature. It is advisable to include the influence of environmental factors, particularly temperature, in the future kinetic model, as it directly relates to storage conditions. A well-known model that connects the rate of chemical reactions with changes in temperature is the Arrhenius model, which is described by the Arrhenius equation [15]:

$$\ln k = \ln A - \left(\frac{E_a}{R \cdot T}\right), \quad (1)$$

Where k – rate constant; A – pre-exponential factor; E_a – activation energy, J/mol; R – universal gas constant (8.31 J/(mol·K)); T – temperature, K.

The specified model, which was theoretically developed for chemical reactions but experimentally confirmed as empirical for many complex reactions involving the loss of food quality, has been applied to determine the shelf life of the meal.

The loss of quality factor follows the same scheme as a chemical reaction of the *n*-th order. According to [6,7,16,17], it has been established that the rate of chemical reactions describing the spoilage of food products obeys the laws of zero or first order. To determine the order of the reaction, graphical dependencies of the peroxide value (*PV*) versus time were constructed. If the reaction follows zero order, the dependence of the oxidation parameter on time will be linear, while for a first-order reaction, the linear relationship will be between the logarithm of the oxidation parameter and time. To assess the fit of the data to the selected model, the coefficient of approximation was used. The closer R^2 is to 1, the better the model describes the experimental data. In addition to determining the order of the reaction, the rate constants, *k*, at different temperatures were also determined based on the slope of the obtained dependencies. By establishing the rate constants, *k*, at different temperatures, the activation energy, *Ea*, and the pre-exponential factor, *A*, were determined from the graphical correlation between $1/T$ and ln *k* [7,18,19].

Using fundamental kinetic approaches and the Arrhenius dependence, an equation has been obtained that describes the kinetics of oil oxidation in the meal and allows for the calculation of the oxidation spoilage rate constant, *k*, at any temperature:

$$k = A \cdot e^{\frac{-E_a R}{T}}, \quad (2)$$

The shelf life, τ of sunflower meal at temperature *T* has been determined by the equations:

$$\tau = \frac{PV_1 - PV_0}{k_T}, \quad (3)$$

where PV_0 та PV_1 – initial and final values of the peroxide value, ½ O mmol/kg. The peroxide value at the end of the shelf life should not exceed 0.4% iodine (31.2 ½ O mmol/kg) and is regulated by Veterinary and sanitary standards for feed safety; k_T– rate constant at temperature *T*.

The temperature coefficient of the oxidation reaction acceleration has been established, Q_{10}:

$$Q_{10} = \frac{k_{T_2}}{k_{T_1}}, \quad (4)$$

Where k_{T_2}, k_{T_1}– the reaction rate at temperatures T_2 and T_1, respectively, and $T_2 > T_1$ at 10 K.

Throughout the year, the degree of oxidative deterioration of the oil from the meal was monitored at temperatures of 293–303 K and relative humidity of 35–45%.

The peroxide values were determined in three replicates. At a specified probability level of P = 95%, the relative error did not exceed 1%. *Microsoft Excel* was used to process the data using mathematical methods.

Results of the research and their discussion

The oxidation of the oil in the meal is one of the most significant reactions leading to the deterioration of meal quality. The approach of chemical kinetics is widely used in food research for the quantitative assessment of quality loss as a function of time. Therefore, the shelf life of the meal was predicted based on monitoring the oxidative stability of the oil in the meal, conducted at a temperature of 293 K over 4 months, as well as at elevated temperatures (348 and 383 K) for 4–6 hours (accelerated method). The degree of oxidative deterioration of the oil was monitored using the peroxide value, which gradually increases due to the accumulation of primary oxidation products.

Using linear regression analysis, the order of the reaction for the oxidation of the oil in the meal was first determined. Fig. 1 (a-c) present the graphical dependencies of the peroxide values and the natural logarithm of the peroxide values against time at temperatures of 293, 348, and 383 K.

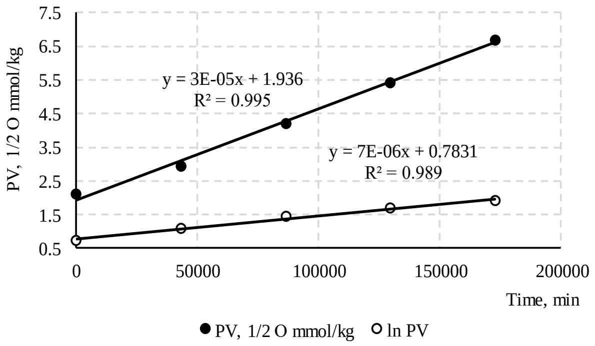
It was established from Fig. 1 that for sunflower oil meal studied under the specified temperature regimes, the approximation coefficients, R^2, for the zero-order dependency (*PV* over time) are closer to one than the coefficients for the first-order dependency (ln *PV* over time). Thus, the linear regression analysis indicated that the zero-order kinetic model best fits the experimental data on the spoilage of sunflower oil meal, as the relationship between peroxide value and time demonstrates a good correlation with a linear equation. A similar linearity of peroxide value over time was also observed for corn and olive oils in [20].

The rate constant for the oxidation of oil meal was determined for each temperature based on the slope of the zero-order dependency graph. The results presented in Table 2 emphasize the influence of temperature on the rate of peroxide oxidation of lipids in sunflower oil meal, showing that the values of the rate constants increase with rising temperature.

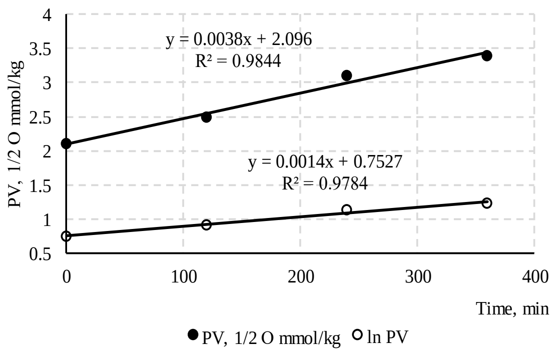
Table 2 – Kinetic parameters of the oxidation reaction of sunflower oil meal

Temperature, K	Coefficient of approximation	Rate constant, ½ O mmol/kg-min
293	0.995	0.00003
298	0.9844	0.0038
303	0.9943	0.0295

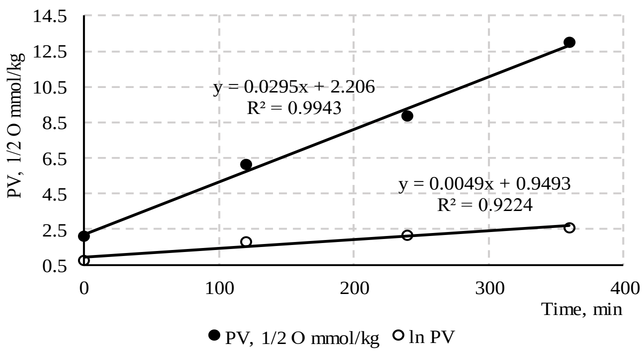
Based on the kinetic data presented in Table 2, an Arrhenius graphical dependence (ln *k* vs. $1/T$) has been constructed, as shown in Fig. 2. This dependence allows for the extrapolation of the rate constant values at different temperatures.



a)



b)



c)

Fig. 1. The dynamics of the change in peroxide value over time at temperature: a) 293 K; б) 348 K; в) 383 K

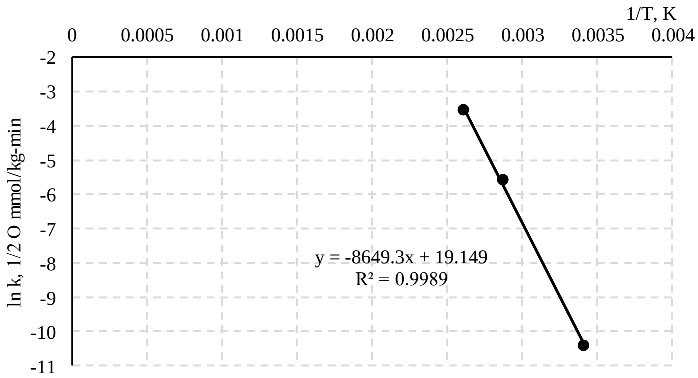


Fig. 2. The dependence of the logarithm of the reaction rate constant on the inverse temperature in the coordinates of the Arrhenius equation.

As seen from Fig. 2, the value of the coefficient of approximation, R^2, is close to 1, indicating that the Arrhenius model is consistent with the experimental data. Based on this graphical relationship, the kinetic equation of the oil oxidation reaction has been derived using equation (1):

$$\ln k = 19{,}149 - \left(\frac{8649{,}3}{T}\right), \qquad (5)$$

which can be expressed based on equation (2) as:

$$k = e^{\left[19{,}149 - \frac{8649{,}3}{T}\right]}, \qquad (6)$$

According to equation (5), the pre-exponential factor and activation energy – the minimum energy required to initiate any reaction – were determined. The reaction rate constants and predicted shelf lives were calculated based on temperature in accordance with equations (6) and (3). The predicted shelf life was calculated based on the acceptable level of peroxide value for the meals. The reaction acceleration coefficient for oxidation was calculated using equation (4). The results of the calculations are presented in Table 3.

Table 3 – Kinetic parameters of the oxidation reaction of sunflower meal oil

Temperature, K	Pre-exponential factor	Activation energy, kJ/mol	Rate constant, ½ O mmol/kg-min	Shelf life, months	Acceleration coefficient of the oxidation reaction
293	19.149	71.88	0.0000313	21.5	2.65
298			0.0000514	13.1	
303			0.0000830	8.1	

The kinetic parameters of the oxidation reaction of sunflower seed meal oil, presented in Table 3, demonstrate an increase in the calculated rate constants of the reaction with rising temperature. Since the rate constant has an inverse relationship with the shelf life, according to equation (3), this leads to a significant reduction in the predicted shelf life of the meals. The calculated value of the activation energy of the reaction is consistent with the results presented by researchers in works [7,15,17].

According to Table 3, the predicted shelf life of the meal at a temperature of 298 K is 13.1 months. This prediction is confirmed by the results of the study on the peroxide number of the meal stored for 12 months at temperatures between 293–303 K and relative humidity of 35–45%. The determined peroxide number is 28.9 ½ O mmol/kg (0.37% iodine), which is below the established standards of Veterinary and Sanitary Norms for Feed Safety. This confirms the quality, safety, and suitability of the meal for consumption over 12 months, provided that storage requirements are met according to DSTU 4638:2006 "Sunflower Meal. Technical Specifications". Thus, the obtained equation (6) can be used to determine the rate constant and predict the shelf life of the meal at any temperature.

Conclusions

1. To determine the shelf life of food products, there are two main approaches: studying the shelf life of the product in real-time and predicting the shelf life without prolonged storage. The second method is more practical for products with a long shelf life, such as meals – a byproduct of oil processing. Meals contain lipids that can undergo oxidative changes under external conditions, potentially degrading their quality and safety during extended storage.

2. To predict the shelf life, the Arrhenius kinetic model has been chosen, which adequately describes the dependence of the rate of various chemical reactions on temperature. This model is effective because temperature directly influences the storage times of products. The peroxide value was specifically used to describe the kinetics of lipid oxidation as a function of temperature. The order of the oxidation reaction of sunflower oil meal was determined based on graphical dependencies of the peroxide value over time. The compliance of the obtained data with the chosen model was assessed using the coefficient of approximation, which confirmed that the oxidation reaction follows zero-order kinetics. Based on the graphical relationship between $1/T$ and $\ln k$, the activation energy (71.88 kJ/mol) and the pre-exponential factor (19.149) were determined. The linear nature of this relationship and the coefficient of approximation R^2 close to 1 indicate that the Arrhenius model aligns well with the experimental data.

3. A kinetic equation has been developed for the oxidation reaction of oil meal, allowing the calculation of the rate constant at various temperatures. Calculations of the rate constants for the reaction at temperatures of 293, 298, and 303 K were conducted. It was found that as the temperature increases, the rate constant increases from 0.0000313 to 0.0000830 ½ O mmol/kg/min. Based on the rate constants, the acceleration coefficient for the oxidation reaction was determined to be 2.65.

4. The projected shelf life of the oil meal at a temperature of 298 K was 13.1 months. The accuracy of this prediction is confirmed by the peroxide value of the meal, which was stored for 12 months at temperatures ranging from 293 to 303 K and a relative humidity of 35–45%. The peroxide value was found to be below the established standards (28.9 compared to 31.2 ½ O mmol/kg). Thus, the proposed method allows for formulating recommendations on optimal storage periods to ensure the quality and safety of the product within a short time frame under various temperature conditions.

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ПРОГНОЗУВАННЯ ТЕРМІНУ ПРИДАТНОСТІ СОНЯШНИКОВОГО ШРОТУ З ВИКОРИСТАННЯМ КІНЕТИЧНИХ МОДЕЛЕЙ

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Анотація. Розглянуто питання визначення терміну придатності шротів із застосуванням кінетичного підходу. Шрот соняшниковий є вторинним продуктом виробництва соняшникової олії і активно використовується в сільському господарстві як висококалорійний компонент комбікормів для вигодівлі птиці, свиней і великої рогатої худоби. Основна цінність шроту полягає в високому вмісті білка (до 44%), клітковини, вітамінів групи В та Е, калію, фосфору, а також інших важливих мінеральних і органічних речовин. Однак він містить до 2% олії, яка з часом схильна до окислення, що може негативно вплинути на якість і безпеку продукту. У дослідженні запропоновано метод прогнозування окисної стабільності соняшникового шроту при тривалих термінах зберігання, використовуючи модель Арреніуса, яка описує залежність швидкості реакції від температури. Для опису кінетики окислення ліпідів у шроті застосовано пероксидне число. Виявлено, що реакція окислення демонструє чітку кінетику нульового порядку, а енергія активації для утворення продуктів первинного окислення становить 71,875 кДж/моль. Розроблено кінетичне рівняння для реакції окиснення олії в шроті, що дозволяє розраховувати константу швидкості при різних температурах. Проведені розрахунки констант швидкості реакції при температурах 293, 298 і 303 К показали, що окислення олії у шроті залежить від температури, з коефіцієнтом температурного прискорення реакції, який дорівнює 2,65. Прогнозований термін придатності шроту при температурі 298 К склав 13,1 місяця. Правильність прогнозу підтверджено вимірюванням пероксидного числа шроту, який зберігався протягом 12 місяців при температурі 293–303 К і відносній вологості 35–45%. Запропонований метод у короткий термін дозволяє, з урахуванням різних температурних умов, надати рекомендації щодо термінів зберігання для забезпечення високої якості та безпеки продукту.

Ключові слова: шрот соняшниковий, окиснення, пероксидне число, константа швидкості, кінетика, термін придатності.