

The object of the study is the catalytic activity of potassium glyceroxide in the chemical transesterification reaction of palm olein.

Transesterification is an important method for obtaining fats with desired properties, surfactants, alternative biofuels, etc. Industrial catalysts for chemical transesterification are explosive, flammable, and quickly lose activity. Alkali metal glyceroxides are safer and more stable catalysts.

The dependence of potassium glyceroxide catalytic activity (CAS Number 43110-90-3) on storage conditions was examined. The criterion for the catalyst's effectiveness was an increase in palm olein melting point by more than 12 °C after transesterification. Refined, bleached, and deodorized palm olein (DSTU 4438:2005, CAS Number 93334-39-5) was used, with the following parameters: peroxide value 0.18 1/2 O mmol/kg, acid value 0.12 mg KOH/g, melting point 22.2 °C.

The conditions under which potassium glyceroxide retains its effectiveness were determined: storage time of 8 weeks at a temperature of 20 °C; storage time of 15 weeks at 5 °C. The melting point difference between original and transesterified olein was 12.5 °C and 13.6 °C, respectively. The chromatographic analysis confirmed changes in the triglyceride composition of the transesterified olein.

It was found that the industrial catalyst sodium methoxide, stored under these conditions, lost its effectiveness. The melting point difference between original and transesterified olein was 7.5 °C and 9.7 °C, respectively.

The obtained data allow for efficient transesterification of fats using potassium glyceroxide as a more stable catalyst, which can be pre-produced and stored at the enterprise

Keywords: potassium glyceroxide transesterification catalyst, palm olein, triglyceride composition, melting point

DETERMINING THE DEPENDENCE OF POTASSIUM GLYCEROXIDE CATALYTIC ACTIVITY ON STORAGE CONDITIONS

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1. Introduction

Transesterification is a reaction of acyl exchange during the interaction of triglyceride molecules. This is a type of

oil and fat modification that allows for altering their physico-chemical properties by changing the triglyceride composition. In a solid state, transesterified fats have a fine-crystalline structure and a homogeneous plastic consistency due

to the formation of the crystalline β' -form. Thus, a mixture of beef fat and sunflower oil (40:60) % has a melting point of (40–41) °C. When slowly cooled, the mixture stratifies. After transesterification, this mixture turns into a homogeneous plastic fat without stratification, with a melting point of (32–33) °C [1].

Transesterification produces mono- and diglycerides, as well as fatty acid esters, which are the basis for biodiesel fuel. Unlike hydrogenation, which can yield up to 50 % of trans-fatty acids, transesterification does not cause isomerization [2].

The transesterification reaction requires the use of catalysts, which help reduce the process temperature from 250 °C to (30–120) °C. However, there are several issues related to their handling and storage.

In chemical transesterification, the most common alkaline catalysts are alkoxides (sodium methoxide, sodium ethoxide). Alkoxides are flammable, can form explosive mixtures with air, and spontaneously ignite. Thus, the explosion limit of sodium methoxide is (7.3–36) % in air (by volume), with an autoignition temperature of (70–80) °C. These substances react violently with oxidants and form flammable methanol and sodium hydroxide when in contact with water. When exposed to air, alkoxides react with carbon dioxide, sulfur dioxide, hydrogen sulfide, moisture, and oxygen, forming sodium hydroxide, sodium carbonate, and other compounds. Alkoxides cause severe burns to the skin and mucous membranes. These catalysts require compliance with storage and handling conditions, including airtight packaging, keeping them away from open flames, employing special loading equipment, etc. Fatty raw materials used for transesterification with alkoxides must have an acid value of no more than 0.1 mg KOH/g and a peroxide value of no more than 0.25 $\frac{1}{2}$ O mmol/kg. The production of such catalysts is also explosion and fire hazardous, making it necessary for oil and fat enterprises to purchase these substances [3].

Other catalysts include alkali metals, their alloys, and hydroxides. However, alkali metals quickly lose activity. Hydroxides require process temperatures above 150 °C, which can degrade product quality. Additionally, part of the hydroxides is spent on fat saponification, reducing reaction efficiency and increasing raw material losses.

Alternative catalysts for chemical transesterification are glycerol salts – alkali metal glyceroxides, obtained through the reaction between glycerol and metals, oxides or hydroxides of metals [4]. Potassium glyceroxide effectiveness has been confirmed by changes in the melting point and triglyceride composition of palm olein. An increase in olein melting point by 12 °C and more is characterized by a change in triglyceride composition beyond measurement error and a shift towards a statistically equilibrium composition [1]. Additionally, potassium glyceroxide has been found to be an effective catalyst for fatty raw materials with high rates of oxidative deterioration. Glyceroxides are viscous, glassy masses that do not pose significant fire hazards and do not create explosion or fire risks when heated. When reacting with water, they form glycerin and the corresponding hydroxide [5].

Thus, the use of industrial catalysts presents challenges related to their reactivity, hazardous properties, and rapid loss of catalytic activity. This necessitates the continuous purchase of new catalyst batches due to the complexity and dangers of their production. It is advisable to introduce alternative catalysts based on alkali metal glyceroxides, devoid of these drawbacks. Given potassium glyceroxide's effectiveness

under high fat oxidation rates, further research is needed to assess its activity under different storage conditions and compare its stability with that of industrial catalysts. Determining the period of its effectiveness, confirmed by changes in the triglyceride composition of the test fat, is of significant importance.

2. Literature review and problem statement

Metal glyceroxides are used in processes that proceed via a transesterification mechanism (alcoholysis, acidolysis, and transesterification itself). Several studies have been dedicated to examining the stability and efficiency of transesterification catalysts under various conditions. For example, the study [6] shows that manganese glyceroxide is an effective catalyst for the synthesis of methyl esters of fatty acids, achieving a final product yield of 99 %. The catalyst remains efficient and stable in the presence of free fatty acids and moisture, including moisture absorbed during storage. However, no data was provided on changes in glyceroxide catalytic activity over time during storage. This could be due to time constraints, as such studies require several months.

Calcium glyceroxides are considered promising and rather stable transesterification catalysts. Calcium glyceroxide synthesized using CaO, glycerin, and methanol in a mass ratio of 1:1.6:13.4 was studied. This catalyst has been found to be stable in air and effective in transesterification reactions involving free fatty acids in the raw material [7]. However, no data are available on the decrease in the glyceroxide catalytic activity during storage in contact with air, nor on comparisons with alkoxides. This could be explained by the necessity of maintaining strict temperature conditions during catalyst storage and ensuring the stability of fat parameters over a long period.

The study [8] explored the synthesis of calcium glyceroxides and their application in the methanolysis reaction of soybean oil. It was shown that calcium glyceroxide can be reused up to five times, with a conversion rate of nearly 82 % after the fourth use. The effectiveness of calcium glyceroxide as a catalyst for glycerol polymerization was also investigated [9], demonstrating its stability and efficiency in the presence of moisture. However, the impact of storage time and moisture accumulation on catalytic activity was not examined. This is primarily because the main focus was on determining the catalyst's overall effect on the methanolysis process and conversion rates in the presence of moisture. Further research on the influence of storage period and catalyst quality requires a significant amount of time.

The study [10] examined the properties and structure of calcium glyceroxide. It was shown that glyceroxide is a viscous mass that is more resistant to environmental factors and safer to use compared to other powdered alkaline catalysts. However, the study did not explore the catalyst's shelf life while preserving its activity. To determine this, an operational and precise criterion for assessing catalyst efficiency must be identified.

During sodium glyceroxide storage, water accumulates due to decomposition, which can be easily separated from glycerin by vacuum distillation [11]. At 100 °C, the relative volatility of water to glycerin is approximately 4000:1, minimizing glycerin losses during co-distillation with water. This suggests that the catalyst's properties can be restored after decomposition during storage, unlike sodium methylate.

Methanol is more volatile than water, requiring complex and energy-intensive fractional distillation. However, the study did not consider the effect of storage time and moisture accumulation on the catalytic activity of sodium glyceroxide. Conducting such research requires fatty raw materials with stable physico-chemical properties.

The use of alkoxides as transesterification catalysts for mixtures containing free fatty acids is impractical [12]. Alkoxides react rapidly with acids to form soaps. It was noted that sodium glyceroxide is a more stable and effective catalyst, allowing for the production of methyl esters with a concentration of 99.1 %. However, the study lacks data on sodium glyceroxide's stability and activity retention during storage. One of the objective reasons for this could be the complexity and duration of determining glyceroxide catalytic activity.

The study [13] investigated lithium glyceroxide, revealing significant advantages over alkali metal methoxides. The drawbacks of methoxides include hazardous and costly production, requiring special premises, as well as high transportation costs due to the flammability and corrosiveness of methanol and methoxides. Lithium glyceroxide was synthesized by heating aqueous solutions of lithium hydroxide with glycerol under vacuum. The dehydration rates for different molar ratios of lithium hydroxide to glycerin were $3:1 < 2:1 < 1:1$. The resulting lithium glyceroxide exhibited greater resistance to moisture and acids compared to methoxides. However, the study did not explore the dependence of glyceroxide catalytic activity loss on storage conditions and time, including comparisons with methoxides. This is likely due to the difficulty of conducting long-term studies under identical conditions, as the physico-chemical properties of raw materials change over months.

The efficiency of zinc glyceroxide as a catalyst in glycerolysis for biodiesel production from oleic acid was studied [14]. Zinc glyceroxide was initially dissolved to form zinc oleate, and then regenerated into zinc glyceroxide during the reaction, which is an important process for oleic acid conversion. Regeneration of zinc glyceroxide was achieved when the molar ratio of glycerol to oleic acid exceeded 0.6:1. This indicates the glyceroxide's effectiveness in acidic reaction media, unlike other alkaline catalysts. However, no data were presented on glyceroxide activity loss during storage, particularly under the influence of acids, moisture, etc. This omission may be due to the difficulty of promptly assessing glyceroxide catalytic activity in glycerolysis reactions.

It is noted that, in addition to safety concerns, the transportation of alkoxides leads to their rapid deterioration and decomposition [15]. Unlike alkoxides, glyceroxide-based catalysts synthesized in a molar ratio of KOH:glycerol 3:1 (potassium glyceroxide) are more stable. The study [16] reported that potassium glyceroxide obtained at 150 °C achieves a conversion rate of 97.45 % in the production of fatty acid methyl esters. The catalyst is effective in transesterification reactions without vacuum application, i.e. in the presence of moisture and air. This highlights the greater stability of glyceroxide compared to alkoxides. However, unresolved issues remain regarding the relationship between the storage period and conditions of glyceroxide and methylate and their catalytic activity. One of the reasons for this is the difficulty of monitoring the catalyst's activity in methanolysis reactions and the need for effective criteria for assessing catalytic activity.

The study [17] investigated the transesterification process using calcium methylate. It was shown that alkoxides quickly lose catalytic activity under the influence of moisture

and free fatty acids in fatty raw materials. However, no data are available on the storage conditions and shelf life of this catalyst. This may be due to the difficulty of working with such an unstable catalyst, which requires special storage and handling conditions.

It was found that potassium glyceroxide is an effective catalyst in palm olein transesterification with high oxidation rates (peroxide value 12.7 $\frac{1}{2}$ O mmol/kg, anisidine value 10.4 c. u.). The olein melting point increased by 12.1 °C after transesterification. Thus, glyceroxide proves effective under the influence of impurities in the reaction mass. However, the study did not examine the effects of storage conditions and time on the catalyst's efficiency in transesterification. This is likely because the olein used in the study was kept at a temperature of 90 °C for 15 hours to enhance oxidation rates, whereas investigating catalyst property changes during storage requires raw materials with stable quality parameters [5].

Thus, glyceroxides demonstrate greater stability and efficiency when exposed to air, moisture, free fatty acids, and fat oxidation products compared to alkoxides. Glyceroxides are also safer to use, and their production does not require complex equipment or conditions. However, there is not enough data on the shelf life of glyceroxides, as well as the impact of storage conditions and time on their quality and catalytic activity, especially in comparison with alkoxides. This issue is relevant, as precise calculations of raw material and catalyst requirements are essential for oil and fat enterprises to ensure continuous production of high-quality products. The use of alkoxides is further complicated by the need for frequent purchase of new batches due to their rapid loss of efficiency. Therefore, an unresolved issue remains determining the dependence of glyceroxide catalytic activity on storage time, as well as defining optimal conditions for maximizing long-term activity retention.

3. The aim and objectives of the study

The aim of the study is to determine the dependence of potassium glyceroxide catalytic activity on storage time and temperature. This will allow for predicting the efficiency of transesterification using potassium glyceroxide based on catalyst storage conditions, as well as calculating the necessary production volumes considering its shelf life.

To achieve the aim, the following objectives were accomplished:

- to determine the conditions (storage time and temperature) under which potassium glyceroxide retains its efficiency in palm olein transesterification;
- to conduct a comparative analysis of the catalytic activity of potassium glyceroxide and sodium methoxide, stored under defined optimal conditions.

4. Materials and methods

4.1. The object and hypothesis of the study

The object of the study is the catalytic activity of potassium glyceroxide in the chemical transesterification of palm olein. The primary research hypothesis is that increasing storage time and temperature reduces the catalytic activity of potassium glyceroxide. The study assumes that during storage, the catalyst partially decomposes into water, potassium hydroxide, and glycerin, and the formation of these compo-

nents affects the efficiency of transesterification catalyzed by this substance. The work adopts the simplification that changes in the physico-chemical properties of palm olein during storage are not considered. The study used standard methods for oil and fat analysis.

4.2. Examined materials and equipment used in the experiment

The study utilized the following materials and equipment:

- refined, bleached, and deodorized palm olein according to DSTU 4438 (CAS Number 93334-39-5);
- Hewlett Packard HP-6890 gas chromatograph.

4.3. Methods for determining quality parameters of the experimental fat

The quality parameters of palm olein were determined by standard methods used for oil and fat analysis: moisture and volatile matter content – ISO 662:2016; acid value – ISO 660:2020; peroxide value – ISO 3960:2017; melting point – EN ISO 6321:2002; triglyceride composition – ISO/TS 17383:2014 (gas chromatography).

4.4. Methods of transesterification of the experimental fat

The processes of palm olein transesterification were carried out according to [5], using potassium glyceroxide as a catalyst, which was stored according to the experimental design.

4.5. Research planning and data processing

The study employed a second-order full factorial design. Mathematical processing of the results and construction of the corresponding response surface were performed using the StatSoftStatistica v6.0 software package (USA). Two repetitions were performed in each experiment. For calculations, the “General Regression Models” module was used, including the following tabs: “Parameter Estimates” (regression equation coefficients, standard error, 95 % confidence interval); “Observed, Predicted, and Residual Values” (response function values); “ANOVA” (analysis of variance).

5. Results of determining the dependence of potassium glyceroxide catalytic activity on storage conditions

5.1. Determining storage conditions for potassium glyceroxide while preserving catalytic activity

The physico-chemical parameters of the experimental sample of refined, bleached, deodorized palm olein (DSTU 4438:2005, CAS Number 93334-39-5) were preliminarily determined and are given in Table 1.

Thus, the experimental palm olein fully complies with DSTU 4438:2005.

The effect of storage time and temperature on the efficiency of potassium glyceroxide in palm olein transesterification was determined. The melting point difference between original and transesterified palm olein was chosen as the response function. The value of 12 °C and above indicates a change in triglyceride concentrations in the fatty raw material beyond the measurement er-

ror [1]. The potassium glyceroxide dosage in each experiment was 0.45 % by weight of olein [5]. The following variation factors were investigated at three levels:

- x_1 – storage time, weeks (from 1 to 15 weeks);
- x_2 – storage temperature, °C (from –10 to 20 °C).

Table 1

Physico-chemical parameters of the experimental palm olein sample

| Parameter | Value | DSTU 4438 standard |
|---|-------|--------------------|
| Melting point, °C | 22.2 | 18–24 |
| Moisture and volatile matter content, % | 0.06 | 0.1 |
| Acid value, mg KOH/g | 0.12 | 0.2 |
| Peroxide value, ½ O mmol/kg | 0.18 | 10.0 |

According to the experimental design, each catalyst sample was stored in a separate darkened glass container, closed loosely with screw cap. Samples were stored at a temperature of –10 °C in a freezer, at 5 °C in a refrigerator, and at 20 °C in a laboratory under shaded conditions.

The data obtained were analyzed using the StatSoftStatistica v6.0 package (USA). The study employed the following response function (second-degree polynomial):

$$y = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2 + b_{11} \cdot x_1^2 + b_{22} \cdot x_2^2, \quad (1)$$

where y – melting point difference between original and transesterified palm olein, °C; b_0 – free term of the regression equation; x_1 – potassium glyceroxide storage time, weeks; x_2 – potassium glyceroxide storage temperature, °C; b_1, b_2, b_{11}, b_{22} – coefficients of the corresponding polynomial terms.

The experimental design matrix, along with the experimental (y_e) and calculated (y_c) values of the melting point difference between original and transesterified palm olein, is shown in Table 2.

Table 2

Design matrix and response function values

| Experiment No. | Factors of variation | | | | Melting point difference of palm olein y_e , °C (experimental value) | Melting point difference of palm olein y_c , °C (calculated value) |
|----------------|---|-------|--|-----|--|--|
| | Potassium glyceroxide storage time, x_1 | | Potassium glyceroxide storage temperature, x_2 | | | |
| | Coded level | Weeks | Coded level | °C | | |
| 1 | −1 | 1 | +1 | 20 | 15.1 | 15.4 |
| 2 | −1 | 1 | 0 | 5 | 18.7 | 18.4 |
| 3 | −1 | 1 | −1 | −10 | 19.1 | 19.6 |
| 4 | 0 | 8 | +1 | 20 | 12.5 | 12.4 |
| 5 | 0 | 8 | 0 | 5 | 15.1 | 15.4 |
| 6 | 0 | 8 | −1 | −10 | 16.7 | 16.1 |
| 7 | +1 | 15 | +1 | 20 | 10.9 | 10.7 |
| 8 | +1 | 15 | 0 | 5 | 13.2 | 13.7 |
| 9 | +1 | 15 | −1 | −10 | 14.7 | 14.9 |

The significance level of all regression coefficients was determined ($p > 0.05$). The regression dependency of the melting point difference between original and transesterified palm olein on the storage time and temperature of potassium glyceroxide, in terms of natural variables, is expressed as follows:

$$y = -19.527 - 0.556 \cdot x_1 - 0.100 \cdot x_2 + 0.014 \cdot x_1^2 - 0.004 \cdot x_2^2. \quad (2)$$

The adequacy of the calculated mathematical model was confirmed using analysis of variance (Table 3).

Table 3

Results of analysis of variance for the calculated mathematical model

| Factor | Sum of squares, SS | Degrees of freedom, df | Mean square, MS | F-value | Significance level, p-value |
|---|--------------------|------------------------|-----------------|-----------|-----------------------------|
| Free term of the equation | 540.0418 | 1 | 540.0418 | 5,820.810 | 0.000000 |
| Storage time, weeks (L) | 5.4467 | 1 | 5.4467 | 58.707 | 0.001560 |
| Storage time, weeks (Q) | 0.8889 | 1 | 0.8889 | 9.581 | 0.036387 |
| Storage temperature, °C (L) | 5.7429 | 1 | 5.7429 | 61.900 | 0.001411 |
| Storage temperature, °C (Q) | 1.5606 | 1 | 1.5606 | 16.820 | 0.014838 |
| Error | 0.3711 | 4 | 0.0928 | – | – |
| Coefficient of determination $R^2=0.994$ | | | | | |
| Adjusted coefficient of determination $R^2_{adj}=0.988$ | | | | | |

Critical points in the regression dependency (2) were analyzed using the StatSoftStatistica v6.0 environment (USA), which helped to determine conditions under which potassium glyceroxide retains its effectiveness. In this case, the melting point difference between original and transesterified olein should exceed 12 °C. These conditions are as follows: storage time of 8 weeks at a temperature of 20 °C; storage time of 15 weeks at 5 °C. The melting point difference between original and transesterified olein was 12.5 °C and 13.6 °C, respectively.

The response surface, which represents the dependence of the melting point difference between original and transesterified olein on the storage time and temperature of potassium glyceroxide, is given in Fig. 1.

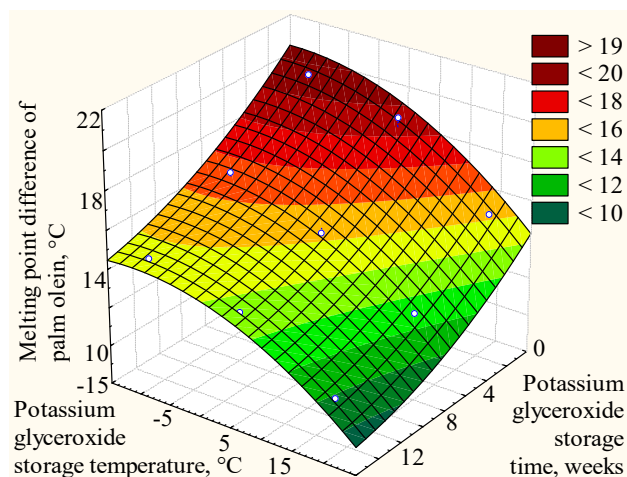


Fig. 1. Dependence of the melting point difference between original and transesterified olein on the storage time and temperature of the potassium glyceroxide catalyst

From Fig. 1, it was found that with increasing storage time and temperature, the melting point difference between original and transesterified olein decreased. To preserve the catalyst's efficiency over an extended period, a reduction in temperature is necessary. Therefore, optimal conditions are storage time of 8 weeks at a temperature of 20 °C or storage time of 15 weeks at 5 °C.

5. 2. Comparative analysis of the catalytic activity of potassium glyceroxide and sodium methoxide stored under defined optimal conditions

A comparative analysis was conducted to evaluate the catalytic activity of potassium glyceroxide and sodium methoxide, stored under defined conditions. For this purpose, the melting point increase of palm olein transesterified using sodium methoxide catalyst samples was studied. The samples were stored similarly to potassium glyceroxide, in separate darkened glass containers, closed loosely with a screw cap. Two samples were tested, which were stored under the following conditions:

- *sample 1*: storage time of 8 weeks at a temperature of 20 °C;
- *sample 2*: storage time of 15 weeks at a temperature of 5 °C.

The results of the study are presented in Table 4.

Table 4

Melting point differences between original and transesterified palm olein

| Catalyst storage conditions | Melting point difference between original and transesterified olein using catalysts, °C | |
|---|---|------------------|
| | Potassium glyceroxide | Sodium methoxide |
| Storage time of 8 weeks at a temperature of 20 °C | 12.5 | 7.5 |
| Storage time of 15 weeks at a temperature of 5 °C | 13.6 | 9.7 |

As seen in Table 4, the increase in olein melting point after transesterification with sodium methoxide is below 12 °C. This indicates a minimal change in the triglyceride composition, suggesting that the transesterification process was ineffective.

Gas chromatography analysis was employed to determine the triglyceride composition of the original palm olein, as well as using both catalysts stored for 15 weeks at a temperature of 5 °C. Table 5 shows the triglyceride (TAGs) concentrations in original olein (a_0), transesterified with potassium glyceroxide (a_1) and sodium methoxide (a_2). Differences in the concentrations of each TAG in original and transesterified olein with potassium glyceroxide (Δa_{01}) and sodium methoxide (Δa_{02}) are also shown, along with absolute measurement errors for each TAG concentration (for original olein Δ_0 , for transesterified with potassium glyceroxide Δ_1 , and with sodium methoxide Δ_2). The fatty acid residues in the triglycerides are denoted as follows: M – myristic, P – palmitic, O – oleic, L – linoleic, S – stearic.

Thus, the concentration differences of all corresponding TAGs after transesterification with potassium glyceroxide exceed the absolute measurement errors in modulus. However, with sodium methoxide, this result was observed only for 10 TAGs. Therefore, potassium glyceroxide catalytic activity was preserved during storage, as evidenced by changes in the melting point and triglyceride composition of palm olein during transesterification. Sodium methoxide induced less significant changes in both the melting point and triglyceride composition of olein.

Table 5

Triglyceride composition of original and transesterified palm olein

| No. | TAG | a_0 | a_1 | a_2 | Δa_{01} | Δa_{02} | Δ_0 | Δ_1 | Δ_2 |
|-------|-----|--------|--------|--------|-----------------|-----------------|------------|------------|------------|
| 1 | MPP | 0.715 | 1.356 | 0.725 | -0.641 | -0.01 | 0.07865 | 0.14916 | 0.07975 |
| 2 | MOM | 0.099 | 0.886 | 0.101 | -0.787 | -0.002 | 0.01089 | 0.09746 | 0.01111 |
| 3 | PPP | 1.548 | 10.253 | 1.635 | -8.705 | -0.087 | 0.17028 | 1.12783 | 0.17985 |
| 4 | MOP | 2.102 | 1.541 | 2.402 | 0.561 | -0.3 | 0.23122 | 0.16951 | 0.26422 |
| 5 | MLP | 0.41 | 0.942 | 0.652 | -0.532 | -0.242 | 0.0451 | 0.10362 | 0.07172 |
| 6 | PPS | 0.005 | 2.358 | 0.123 | -2.353 | -0.118 | 0.00055 | 0.25938 | 0.01353 |
| 7 | POP | 37.856 | 22.097 | 38.237 | 15.759 | -0.381 | 1.8928 | 1.10485 | 1.91185 |
| 8 | PLP | 8.963 | 3.843 | 8.365 | 5.12 | 0.598 | 0.71704 | 0.42273 | 0.6692 |
| 9 | MLO | 0.125 | 0.428 | 0.089 | -0.303 | 0.036 | 0.01375 | 0.04708 | 0.00979 |
| 10 | PSS | 1.952 | 3.013 | 1.852 | -1.061 | 0.1 | 0.21472 | 0.33143 | 0.20372 |
| 11 | POS | 4.005 | 2.097 | 3.558 | 1.908 | 0.447 | 0.44055 | 0.23067 | 0.39138 |
| 12 | POO | 16.023 | 28.344 | 17.523 | -12.321 | -1.5 | 1.28184 | 1.4172 | 1.40184 |
| 13 | PLS | 8.963 | 4.146 | 8.523 | 4.817 | 0.44 | 0.98593 | 0.45606 | 0.93753 |
| 14 | PLO | 7.993 | 3.099 | 7.123 | 4.894 | 0.87 | 0.87923 | 0.34089 | 0.78353 |
| 15 | PLL | 0.369 | 3.054 | 0.122 | -2.685 | 0.247 | 0.04059 | 0.33594 | 0.01342 |
| 16 | SOS | 0.485 | 1.402 | 0.325 | -0.917 | 0.16 | 0.05335 | 0.15422 | 0.03575 |
| 17 | SOO | 3.125 | 1.835 | 3.023 | 1.29 | 0.102 | 0.34375 | 0.20185 | 0.33253 |
| 18 | OOO | 3.652 | 5.755 | 3.956 | -2.103 | -0.304 | 0.40172 | 0.63305 | 0.43516 |
| 19 | SLO | 0.852 | 0.536 | 0.753 | 0.316 | 0.099 | 0.09372 | 0.05896 | 0.08283 |
| 20 | OLO | 0.758 | 3.015 | 0.913 | -2.257 | -0.155 | 0.08338 | 0.33165 | 0.10043 |
| Total | | 100 | 100 | 100 | - | - | - | - | - |

6. Discussion of the results of determining the dependence of potassium glyceroxide activity on storage conditions

This study examined the dependence of potassium glyceroxide catalytic activity on storage conditions. The catalytic activity was estimated by an increase in palm olein melting point during transesterification. A second-order full factorial design was applied. As factors of variation, storage time and temperature at three levels were investigated (Table 2). Analysis of variance was performed, and the adequacy of the mathematical model was confirmed (Table 3).

According to Fig. 1, it was found that with increasing storage time and temperature, the melting point difference between original and transesterified olein decreased. Critical points in the dependency (2) were analyzed using the StatSoftStatistica v6.0 environment (USA), which helped to determine conditions under which potassium glyceroxide retains its activity. These conditions are as follows: storage time of 8 weeks at a temperature of 20 °C; storage time of 15 weeks at 5 °C. Under these conditions, the melting point difference between original and transesterified olein was 12.5 °C and 13.6 °C, respectively, exceeding 12 °C. This confirms that the catalyst was effective. In the case of transesterification with sodium methoxide, stored under similar conditions, this figure was 7.5 °C and 9.7 °C, respectively (Table 4). The error in the calculation using equation (2) did not exceed 4 %.

Gas chromatography analysis was used to determine changes in triglyceride concentrations after transesterification with potassium glyceroxide and sodium methoxide, stored for 15 weeks at a temperature of 5 °C. The analysis showed that changes in triglyceride concentrations beyond the measurement error occurred for all triglycerides when potassium glyceroxide was used. In the case of sodium methoxide, this only happened for 50 % of the triglycerides. This is

explained by the partial decomposition of sodium methoxide during storage due to its high reactivity and ability to interact with air components.

Available studies [5–13] report that metal glyceroxides can catalyze transesterification processes in the presence of moisture formed during storage. For instance, [6] shows that manganese glyceroxide is an effective transesterification catalyst in the presence of moisture and free fatty acids. Additionally, calcium glyceroxides are more stable during storage and moisture exposure than alkoxides [7–10]. In contrast to [5–13], this study determined the effect of storage time and temperature on the catalytic activity of potassium glyceroxide. During storage, potassium glyceroxide decomposes, forming water and potassium hydroxide. The accumulation of these products reduces the concentration of the active substance and thus the catalyst's activity. The data obtained show the effectiveness of potassium glyceroxide stored under defined conditions, although it underwent partial decomposition. These findings correlate with the data given in [5–13]. The study [5] provides data on potassium glyceroxide effectiveness in palm olein transesterification reactions with high oxidation rates, further confirming the high stability of this catalyst against deactivating factors.

A limitation of this study is that the experiments were conducted using high-purity palm olein. So, the application of potassium glyceroxide, which underwent storage, for raw material transesterification with a high moisture content requires additional investigation to assess the catalyst's effectiveness.

Another shortcoming of the work is the lack of data on potassium glyceroxide effectiveness in transesterification reactions of fat mixtures of different quality. After all, the production of transesterified fat mixtures is crucial in the industry, and the processing of raw materials with high spoilage rates remains a relevant issue.

A promising avenue for further research would be to investigate changes in the quality parameters of potassium glyceroxide during storage, such as moisture content and the concentration of the active component. These parameters are also vital for assessing the catalyst's quality during storage.

7. Conclusions

1. The conditions under which the potassium glyceroxide catalyst retains its effectiveness were determined: storage time of 8 weeks at a temperature of 20 °C; storage time of 15 weeks at 5 °C. The catalyst's effectiveness was assessed by an increase in palm olein melting point during the transesterification reaction. Under these conditions, the melting point difference between original and transesterified palm olein was 12.5 °C and 13.6 °C, respectively, exceeding 12 °C. This confirms that the catalyst was effective.

2. A comparative analysis of the catalytic activity of potassium glyceroxide and sodium methoxide, stored under defined conditions was carried out. In the case of palm olein transesterification with sodium methoxide, stored under defined conditions, the melting point difference of olein is 7.5 °C and 9.7 °C, respectively. Changes in the triglyceride composition of palm olein resulting from transesterification with potassium glyceroxide and sodium methoxide were examined. The concentration differences of 100 % triglycerides after transesterification with potassium glyceroxide exceed the absolute measurement

errors in modulus. However, in palm olein transesterification with sodium methoxide, this result was observed only for 50 % triglycerides. Therefore, potassium glyceroxide is more stable during storage than sodium methoxide.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, 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 current work.

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