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Original Article

Evaluation of Different Storage Techniques for Maintaining Oil Quality of Oilseeds

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Abstract

This study evaluates the effects of storage conditions and container types on the quality of soybean, sesame, and palm oils over 12 weeks using free fatty acid (FFA), UV–Vis absorbance, and physical observations. Oils were stored in aluminium, plastic, and glass containers under refrigeration, cabinet, and room conditions. Results showed a progressive increase in FFA and absorbance, indicating ongoing degradation. Storage temperature was identified as the dominant factor, with refrigeration significantly slowing degradation compared to higher temperatures. Container type showed a secondary effect, where plastic promoted higher FFA formation, while glass provided better stability. Distinct behaviours were observed among the oils. Soybean oil exhibited the most pronounced degradation; sesame oil showed increased absorbance under refrigeration, likely due to crystallisation effects, and palm oil maintained stable absorbance despite physical changes. Overall, oil stability is governed by the interaction of temperature, container material, and oil composition

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1. Introduction

Vegetable oils such as soybean oil, sesame oil, and palm oil are one of the most widely consumed commodities globally due to their nutritional value and their wide use in various industrial sectors [1,2]. The demand for vegetable oils continues to increase along with the development of applications in the fields of food, nutraceuticals, and biomass-based industries [3]. However, vegetable oils are naturally susceptible to degradation through oxidation, hydrolysis, and polymerization processes, which are influenced by environmental factors such as temperature, light, oxygen, and humidity [4].

The oil's susceptibility to degradation is greatly influenced by its fatty acid composition. Soybean oil has a high content of polyunsaturated fatty acids, especially linoleic and linolenic acids, making it easier to oxidize during storage [5]. Sesame oil, although also rich in unsaturated fatty acids, contains natural antioxidant compounds such as lignans and sesamol that provide better oxidative stability [6]. In contrast, palm oil has a higher proportion of saturated fatty acids as well as a significant carotenoid content, making it relatively more stable against oxidative degradation [3]. These differences in composition lead to variations in resistance to degradation, so the three oils are relevant to use as models for stability evaluation during storage.

In addition to the intrinsic composition of oil, the type of packaging or storage container also plays an important role in determining the stability of the oil. Previous studies have shown that packaging materials have different characteristics in terms of permeability to oxygen and moisture, as well as their interaction with light and reactive compounds [7]. Plastic containers are generally semi-permeable, allowing the entry of oxygen and water vapour [8], while glass is inert and relatively non-permeable. On the other hand, metal-based containers such as aluminium have the potential to influence oxidation reactions through certain catalytic mechanisms [9]. However, comparative studies evaluating the interaction between container type and storage environmental conditions on oil stability are still limited, especially in oils with different compositional characteristics.

The stability of vegetable oils is not only important in the food context, but it also has implications in bioenergy and bioprocess applications, where lipid integrity plays a role in process efficiency and product quality. Variations in environmental conditions, particularly temperature and storage characteristics, have been reported to affect the performance of biomass-based materials [10]. In addition, the chemical stability of oil also affects the efficiency of lipid extraction and degradation pathways during the biomass processing process, including in mushroom-based systems [11]. This shows that oil stability is a cross-sectoral issue that requires systematic evaluation.

Although various studies have examined the effects of temperature or packaging type separately, an integrated understanding of how storage conditions and container types interact in influencing oil degradation across different oil matrices is still limited. Therefore, this study aims to evaluate the effect of the combination of storage conditions and container type on the quality of soybean oil, sesame oil, and palm oil during the 12-week storage period. Oil degradation was analysed through measurements of free fatty acid (FFA) levels, UV–Vis absorbance, and physical observation to gain a comparative understanding of oil stability under various storage conditions.

2. Materials and Methods

2.1. Oil Sample

Three types of vegetable oils were used in this study, namely soybean oil, sesame oil, and red palm oil. The three oils were selected based on differences in the composition of fatty acids and their oxidative stability characteristics. Soybean oil is known to have a high content of polyunsaturated fatty acids, making it more susceptible to oxidation [5], while sesame oil contains natural antioxidant compounds such as lignans and sesamol that provide moderate stability [6]. Palm oil, with a higher content of saturated fatty acids and carotenoids, shows better oxidative stability than unsaturated oils [3]. All oils are sourced from local retailers in Malaysia in their original sealed packaging conditions, with relatively similar production dates to minimise initial quality variations. Before treatment, the oil is transferred into an experimental container with a uniform volume.

2.2. Container Types

Three types of containers with different materials are used, namely amber glass bottles, food-grade plastic containers, and aluminium containers. All containers have a maximum capacity of ±250 mL and are equipped with a tight lid to minimise direct contact with the external environment. Before use, the entire container is cleaned and dried to avoid contamination. The selection of container materials is based on the difference in the properties of permeability to oxygen and moisture, as well as the potential interaction with oil. Plastic containers, specifically high-density polyethylene (HDPE, grade 2) bottles, are known to be semi-permeable to gases and water vapour with screw caps [8]. In contrast, amber glass is inert and relatively impermeable, while metal materials have the potential to affect oxidation reactions through catalytic mechanisms. Aluminium containers, although offering strong barrier properties, may influence oxidation processes through catalytic mechanisms, particularly in the presence of trace metals [7,9]. All containers were fitted with screw caps made of the same material as the respective container to ensure material consistency and minimise cross-material interactions.

2.3. Sample Preparation

A total of 200 mL of each oil was put into each container, resulting in a total of 27 samples (3 types of oil × 3 types of containers × 3 storage conditions). Samples are stored under three environmental conditions, namely: (1) refrigeration (~4°C) (Haier, China), (2) dark cabinet (~25°C), and (3) room temperature (~27°C). The selection of temperature variations is based on differences in commonly used storage conditions as well as the effect of temperature on the rate of oil degradation, where low temperatures are known to slow down the oxidation and hydrolysis processes, while higher temperatures accelerate the formation of degradation products [12,13]. In addition, variations in lighting conditions and storage environments have also been reported to affect oil stability during storage [14]. During storage, containers are placed separately for each treatment combination to avoid cross-contamination. The ambient humidity is not specifically controlled, so the storage conditions represent real conditions (ambient conditions). The study was conducted over a period of 12 weeks with observation intervals every two weeks, which is commonly used to monitor gradual changes in oil degradation during storage [11].

2.4. Oil Quality Parameters

The concentration of free fatty acids was measured using the colorimetric test strip method (Merck Supelco MQuant®, range 0 mg KOH/g, 0.3 mg KOH/g, 0.5 mg KOH/g, 1.5 mg KOH/g, 2.5 mg KOH/g, 3.0 mg KOH/g and 5.0 mg KOH/g). Measurements are made by dipping a strip into an oil sample and comparing the discoloration with the standard scale provided. FFA values are used as indicators of hydrolytic and oxidative degradation of oils, since an increase in FFA reflects the breakdown of triglycerides during the storage process [15,16]. The colorimetric test strip method is used as a quick and practical approach for initial evaluation of oil quality compared to conventional titration methods [17].

2.5. UV–Vis Absorbance Analysis

Oil absorbance was measured using a UV–Visible spectrophotometer (Hach DR6000, range 190–1100 nm) at a wavelength of 465 nm. These wavelengths are chosen to detect changes in chromophore compounds such as carotenoids and oxidation products that form during the storage process [18,19]. UV–Vis analysis has been widely used to monitor changes in the chemical composition of oils, especially with regard to oxidative degradation and pigment changes during storage [16]. The absorbance value is used as an indicator of changes in the chemical composition of the oil during the storage period.

2.6. Physical Observation of Oil Colour

Changes in the physical properties of the oil were observed visually in week 0 and week 12, including colour and viscosity. Discolouration is one of the indicators of oil degradation due to oxidation and chemical composition changes during storage [19], while viscosity changes can reflect the occurrence of polymerisation reactions and the formation of degradation compounds [16]. Documentation was carried out using a digital camera (Sony A6400 16-50mm lens), with pictures taken for all samples under uniform lighting conditions to ensure consistency of comparisons between samples.

2.7. Data Recording and Analysis

Data on free fatty acid (FFA) levels and absorbance values were recorded periodically over 12 weeks and presented in the form of graphs to illustrate trends in oil quality changes. Data processing and visualization were carried out using Microsoft Excel software (Microsoft Corp., USA) to calculate the average value and compile a graph of FFA change and absorbance over time. The analysis was carried out in a comparative descriptive manner to evaluate the influence of container type and storage conditions on oil stability. This approach is used to identify patterns of changes in oil quality during storage, which are commonly applied in oil stability studies based on oxidative parameters [16].

3. Results

3.1. Soy Oilseed

3.1.1. Free Fatty Acid for Soy Oilseed

Figure 1 shows the free fatty acid (FFA) content profile of soybean oil stored in nine combinations of container types and environmental conditions over a 12-week period. In general, the increase in FFA occurs gradually throughout treatment, reflecting the ongoing degradation process during storage.

In week 0 to week 2, all samples showed an FFA value of 0.0 mg KOH/g, indicating that degradation had not occurred significantly in the early stages of storage. An increase in FFA began to be observed in week 4 at most storage conditions, especially at room and cabinet temperatures, while samples stored in refrigerated conditions remained stable at FFA values.

Entering week 8 to week 10, all samples showed relatively uniform FFA values, which was about 0.3 mg KOH/g. This indicates that degradation processes begin to occur in general at all storage conditions, albeit at different rates. At the end of the storage period (12th week), further improvement was seen mainly in samples stored in plastic containers, which reached values up to 0.5 mg KOH/g, while samples in glass and aluminium containers tended to remain at values of 0.3 mg KOH/g.

This pattern shows that storage temperature has a more dominant influence than container type in controlling FFA formation, where refrigeration conditions consistently slow down the rate of degradation compared to room temperature. This is in line with previous research that stated that low temperatures can inhibit lipid oxidation and hydrolysis reactions by lowering the kinetic energy of the reaction [12,13].

In addition, the higher FFA increase in plastic containers indicates that the semi-permeable properties of the material allow the diffusion of oxygen and moisture which can accelerate the oil degradation process [8]. In contrast, glass and aluminium containers show better stability, which has to do with their more inert properties and having lower permeability to gases.

It should be noted that the FFA value in this study was obtained using the colorimetric test strip method which is semi-quantitative with limited resolution. Therefore, small variations between measurements cannot be precisely differentiated and the data obtained do not meet the assumptions for inferential statistical analysis such as standard deviation calculations. The analysis in this study focused on trend-based analysis and relative comparisons between treatments, which remain relevant for evaluating the direction of oil degradation during storage [16].

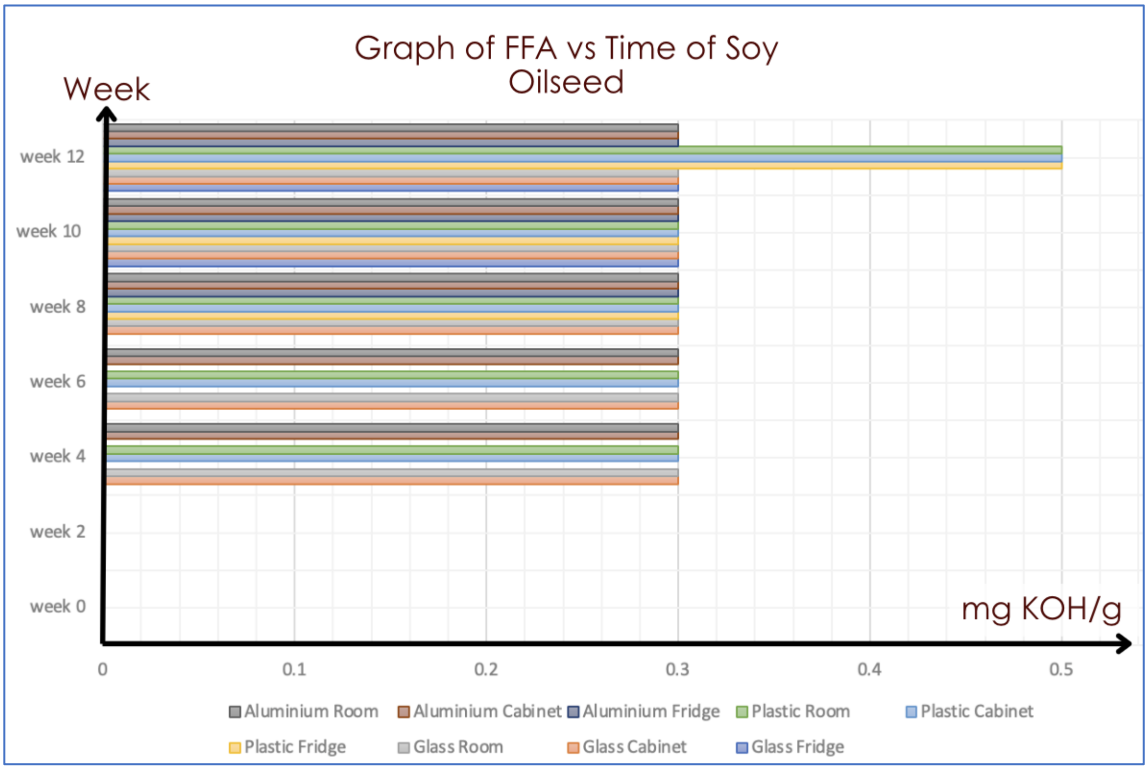

Figure 1. Graph of free fatty acid vs. time of soy oilseed.

3.1.2. Absorbance for Soy Oilseed

Figure 2 shows the change in absorbance value at the 465 nm wavelength as an indicator of oxidation progression in soybean oil stored in nine combinations of container types and environmental conditions over a 12-week period. In general, the entire treatment shows an increasing trend of absorbance over time, which indicates the accumulation of oxidation compounds and changes in pigment composition during storage.

At the beginning of observation (week 0), all samples had a relatively uniform absorbance value, which was about 0.022. An initial improvement began to be observed in week 2, especially in samples stored at cabinet temperature and room temperature, while samples under refrigerated conditions showed very minimal changes. This suggests that low temperatures are able to delay the formation of chromophore compounds detected at these wavelengths.

As the storage time increases, the increase in absorbance becomes more and more pronounced, especially in room temperature conditions. In the mid-phase (weeks 4 to 8), samples stored at room temperature, particularly in aluminium and plastic containers, showed a faster improvement than other conditions. In the final phase (week 10 to week 12), the highest absorbance values were consistently found at room temperature conditions, with maximum values reaching about 0.073 in aluminium containers, followed by glass and plastic. In contrast, samples under constant refrigeration conditions showed lower absorbance values, despite gradual improvements.

This pattern indicates that storage temperature is a dominant factor in accelerating the formation of secondary oxidation products, which can be detected through increased absorbance at 465 nm wavelengths. This is in line with the literature that states that increased temperature accelerates lipid oxidation reactions and the formation of chromophore compounds such as conjugated oxidation products and pigment degradation [16,19].

In addition to the temperature factor, the type of container also shows an influence on variations in absorbance values. Aluminium and plastic containers tend to show higher absorbance values than glass under some conditions, which indicates a possible material contribution to the oxidation process. Metal materials such as aluminium have the potential to act as catalysts in lipid oxidation reactions, while plastics allow oxygen diffusion which can accelerate the formation of oxidation products [8,9]. However, compared to the type of container, the influence of temperature remains more dominant in determining the rate of increase in absorbance.

It should be noted that the absorbance values in this study are presented as single data for each treatment condition without replication, thus not allowing the calculation of statistical dispersion parameters such as standard deviation. In addition, although absorbance measurements are quantitative, the research approach is focused on trend-based analysis between storage conditions. Therefore, the interpretation of the results is focused on the pattern of relative increased absorbance, rather than on the very small numerical differences between treatments. This approach remains relevant in oil stability studies to identify the direction of oxidative degradation during storage [16].

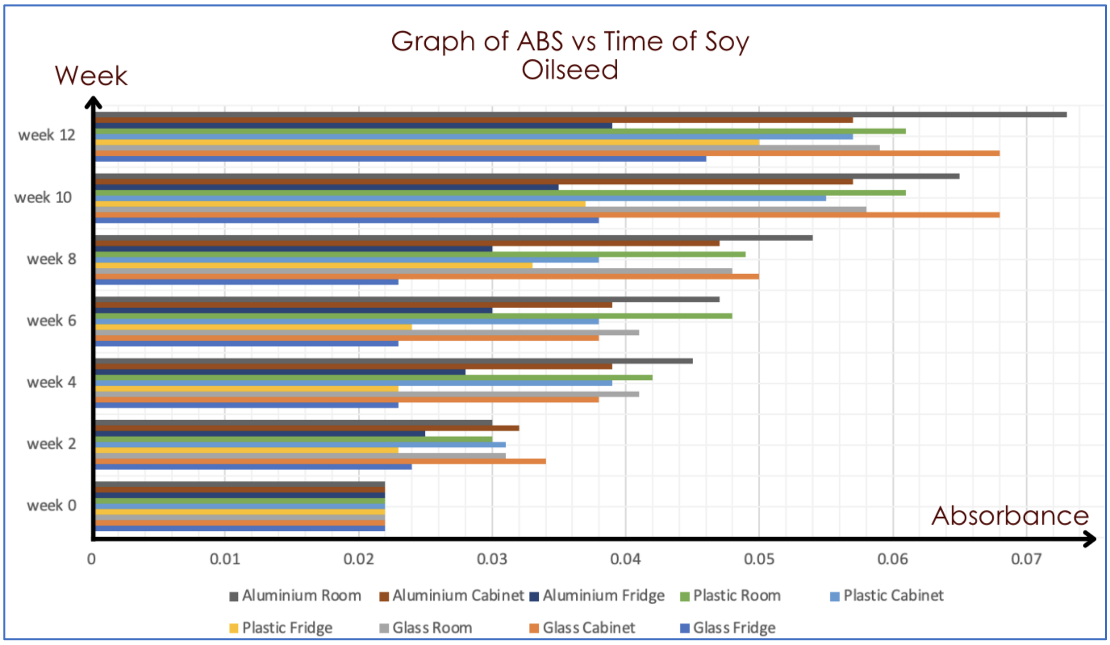

Figure 2. Graph of absorbance vs. time of soy oilseed.

3.1.3. Physical Observation of Soy Oilseed

Figure 4 shows changes in the physical properties of soybean oil after 12 weeks of storage at various combinations of container types and environmental conditions. The codes A, P, and G represent aluminium, plastic, and glass containers, respectively, while the vertical arrangement from left to right shows storage conditions in refrigeration, cabinets, and room temperatures.

Visually, soybean oil stored in refrigerated conditions showed a relatively similar colour to the initial condition (0th week, Figure 3), which indicated better stability during storage. In contrast, samples stored at cabinet conditions and room temperature showed a slightly darker colour change than the initial condition. This discolouration is related to the oxidation process that produces coloured compounds and pigment degradation during storage [16,19].

These findings are consistent with the results of FFA and absorbance analysis, where room temperature conditions show a higher degree of degradation than refrigeration. This reinforces that the increase in temperature accelerates lipid oxidation reactions and the formation of degradation products that can affect the visual properties of the oil.

Meanwhile, no visually significant viscosity changes were observed in all storage conditions compared to the initial conditions. This suggests that although chemical degradation has been detected through increased FFA and absorbance, advanced processes such as polymerization that can affect viscosity are likely to not have occurred predominantly in the observed storage period. Viscosity changes are generally related to the formation of long-chain compounds due to advanced oxidation reactions, which usually occur under more intensive degradation conditions [16].

Figure 3. Initial colour of soy oilseed.

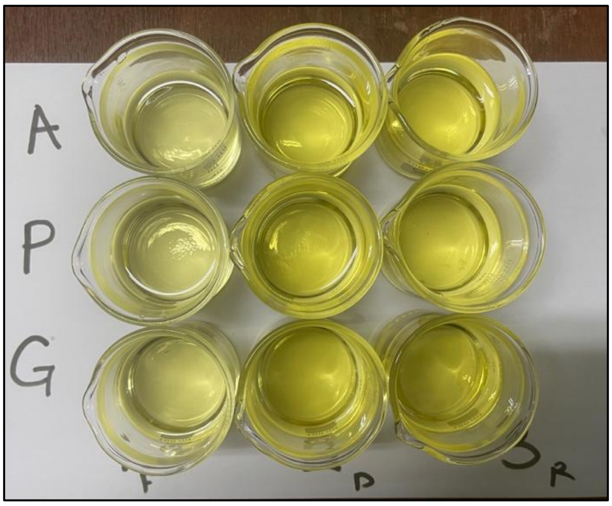

Figure 4. Soy oilseed after 12 weeks.

3.2. Sesame oilseed

3.2.1. Free Fatty Acid for Sesame Oilseed

The free fatty acid (FFA) of sesame oilseed stored under nine different container and environment combinations were monitored over a 12-week period as shown on the bar chart on Figure 5.

From week 0 to week 2, the sesame oil in all storage conditions showed a consistent FFA value at 0.3 mg KOH/g. The FFA value started to increase in week 4, with four out of nine storage conditions which were aluminium cabinet, plastic room, plastic cabinet, and glass cabinet have increased from 0.3 mg KOH/g to 0.5 mg KOH/g, whereas the other five storage conditions stayed at the 0.3 mg KOH/g mark. By week 6, the aluminium fridge and glass fridge can be seen at 0.3 mg KOH/g, showing a constant FFA value, while the remaining seven conditions, being aluminium room, aluminium cabinet, plastic room, plastic cabinet, plastic fridge, glass room, and glass cabinet, have increased slightly to 0.5 mg KOH/g. At week 8, the glass fridge was the only storage condition that was still recorded as 0.3 mg KOH/g, meanwhile all of the other samples have increased to 0.5 mg KOH/g. By week 10, aluminium room, aluminium cabinet, aluminium fridge, plastic room, plastic cabinet, and plastic fridge were recorded reaching 1.5 mg KOH/g, whereas the glass room, glass cabinet, and glass fridge showed constant value of FFA at 0.5 mg KOH/g. At the end of week 12, the aluminium room, aluminium cabinet, plastic room, plastic cabinet, and plastic fridge were the highest recorded FFA value, reaching 2.5 mg KOH/g, while the aluminium fridge stayed at 1.5 mg KOH/g, and all of the sesame oil in the glass container, which were glass room, glass cabinet, and glass fridge, were seen constant at 0.5 mg KOH/g.

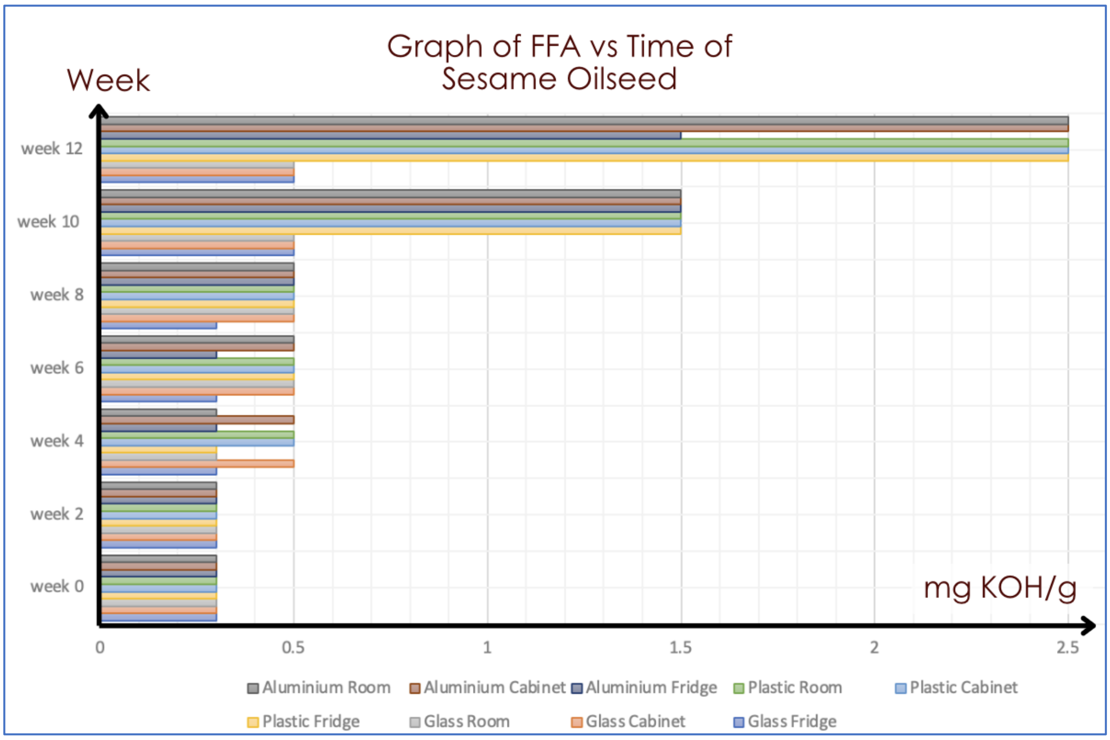

Figure 5. Graph of free fatty acid vs. time of sesame oilseed.

3.2.2. Absorbance for Sesame Oilseed

The absorbance values of sesame oilseed stored in nine different container and environment combinations were monitored over a 12-week period as shown on the bar chart on Figure 6, starting with the value of 0.184 at week 0 on all samples.

At week 2, the absorbance value recorded showed a variety or results, with glass fridge recorded as the highest value at 0.363, followed by aluminium fridge (0.222), and plastic fridge (0.206), while plastic cabinet and plastic room showed a slight increase at 0.197 and 0.190 respectively, while little increase were recorded in glass room (0.185), glass cabinet (0.180), aluminium cabinet (0.186) and aluminium room (0.182). By week 4, the absorbance value showed increased value in the refrigerated samples, with aluminium fridge increased to 0.226, plastic fridge to 0.224 and glass fridge decreased to 0.206. Meanwhile, the aluminium room (0.197), aluminium cabinet (0.190), plastic room (0.193) and plastic cabinet (0.199) increased slightly whereas glass cabinet value were recorded decreased to 0.175 and glass room stayed constant at 0.184. At week 6, aluminium fridge (0.224), plastic fridge (0.220) and glass fridge (0.208) remained the highest absorbance value, while plastic room and glass room value decreased to 0.162, and 0.167 respectively, and plastic cabinet increased slightly to 0.202 and glass cabinet remained the lowest absorbance value at 0.173. By week 8, the aluminium fridge increased to 0.234, plastic fridge to 0.289, ang glass fridge increased to 0.292. The other storage conditions being aluminium room (0.198), aluminium cabinet (0.192), glass room (0.165), and glass cabinet (0.161) recorded were shown stable value of absorbance. At week 10, glass fridge showed a significant increase reaching 0.553, followed by plastic fridge (0.295), and aluminium fridge (0.259), while the absorbance values on the other storage conditions showed slight increase value including aluminium cabinet (0,195), and glass room (0.176). By week 12, aluminium fridge showed the highest value of absorbance recorded, at 0.653, followed by plastic fridge at 0.545 and glass fridge, decreasing to 0.401, while the other sample remained stable, ranging from 0.171 to 0.198.

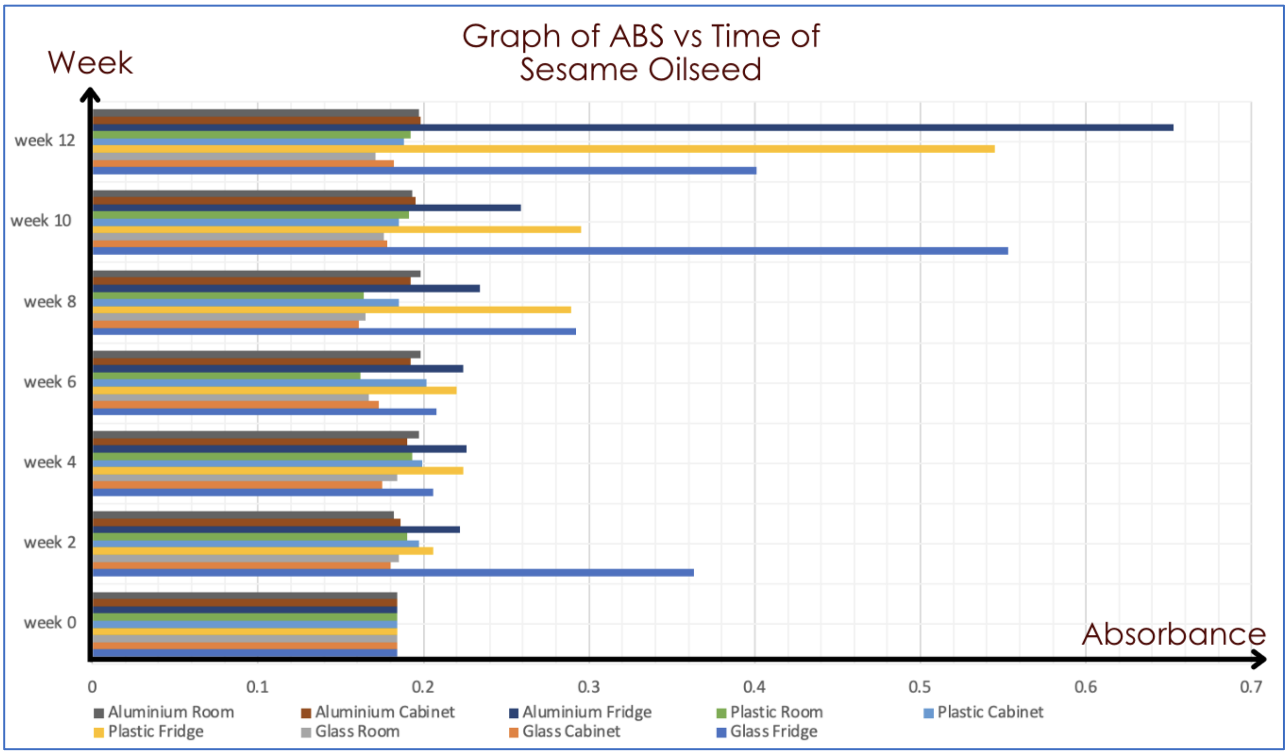

Figure 6. Graph of absorbance vs. time of sesame oilseed.

3.2.3. Physical observation on sesame oilseed

The A in Figure 8 stands for aluminium, P stands for plastic and G stands for glass. From left to right, vertically, was the sesame oil stored in fridge, cabinet and room.

Based on Figure 8, the sesame oilseed that were stored in refrigerator has turned murky, compared to the yellow shades from the initial colour of the sesame oilseed in week 0, shown in Figure 7. The oil viscosity of sesame oilseed stored in refrigerator is higher compared to the oil that were stored in room and cabinet, and the initial viscosity. The colour of sesame oilseed that were stored in the cabinet and in room on the other hand has a similar shade of yellow as compared to the initial colour.

Figure 7. Initial colour of sesame oilseed.

Figure 8. Sesame oilseed after 12 weeks.

3.3. Palm oil

3.3.1. Free Fatty Acid for Palm Oil

Figure 9 shows changes in free fatty acid (FFA) levels in palm oil stored in nine combinations of container types and environmental conditions over a 12-week period. In general, FFA values show a gradual increase during storage, which reflects the occurrence of degradation through hydrolysis and lipid oxidation reactions.

In the early stages (week 0 to week 2), the entire sample showed relatively stable FFA values at 1.5 mg KOH/g, indicating that the degradation had not taken place significantly. An increase began to be observed in week 4, where samples in plastic containers, particularly in cabinet conditions, showed the highest increase to 3.0 mg KOH/g, while most other conditions increased to 2.5 mg KOH/g. In contrast, samples stored in refrigerated conditions tend to retain lower FFA values at this stage.

Along with storage time, the FFA increase becomes more widespread throughout the treatment. In the mid to late phase (week 8 to week 12), the highest FFA values were consistently found in samples stored in plastic containers, especially at room and cabinet temperature conditions, which reached up to 3.0 mg KOH/g. Meanwhile, samples in aluminium and glass containers showed relatively lower and stable FFA values in the range of 2.5 mg KOH/g.

This pattern suggests that, although palm oil is known to have higher oxidative stability than unsaturated oils, degradation still occurs during storage, mainly influenced by temperature conditions and container type. Higher FFA increases in plastic containers indicate that the permeable properties of such materials allow the diffusion of oxygen and moisture which accelerates the hydrolysis reaction [8].

In addition, the influence of temperature remains seen as an important factor, where the temperature conditions of the room and cabinet accelerate the formation of FFA compared to refrigeration. This is in line with previous studies that showed that rising temperatures accelerate oil degradation through an increased rate of chemical reactions [12].

However, compared to soybean oil, the increase in FFA in palm oil is relatively more controlled, which can be attributed to a higher saturated fatty acid content as well as the presence of natural antioxidant compounds such as carotenoids, which play a role in increasing the oxidative stability of the oil [20].

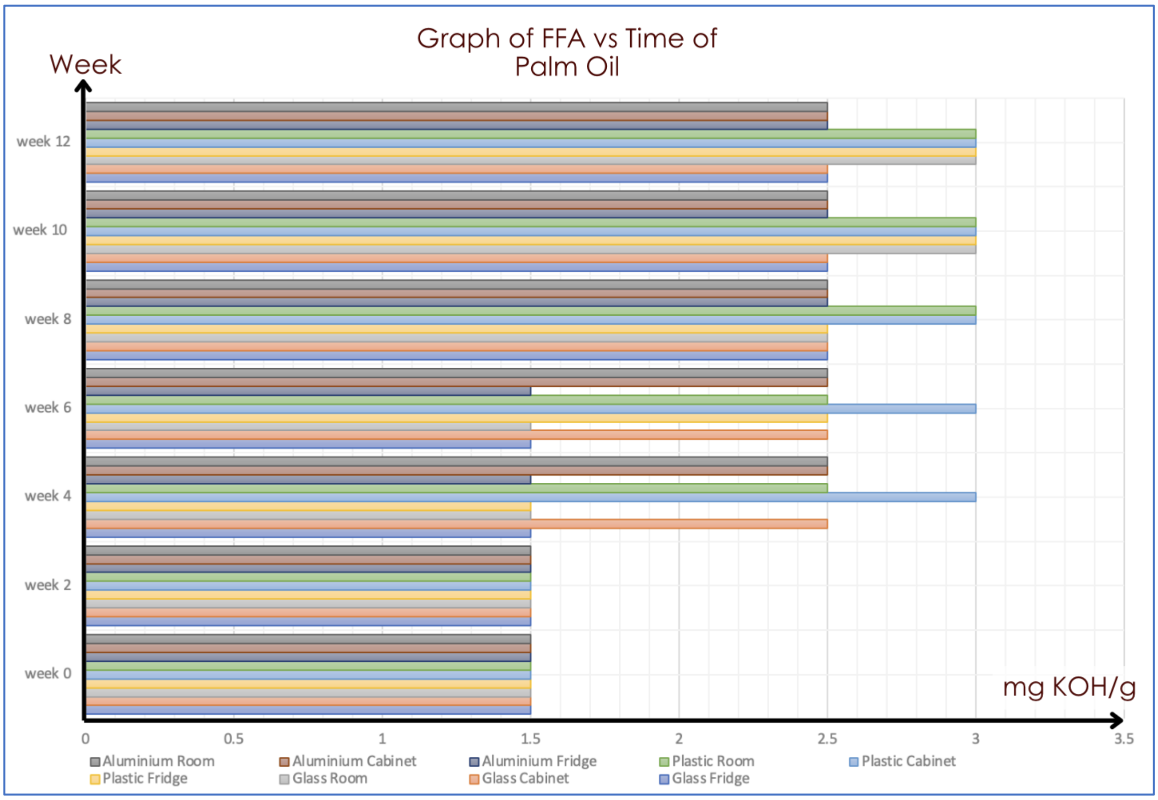

Figure 9. Graph of free fatty acid vs. time of palm oil.

3.3.2. Absorbance for Palm Oil

The absorbance values of palm oil stored across nine different containers and environment combinations were monitored throughout a 12-week period. However, unlike soy oil and sesame oil, the absorbance value for all palm oil samples have remained constant at a value of 1.000 across all storage conditions and time intervals. No changes were observed from week 0 to week 12, regardless of whether the oil was stored in aluminium, plastic, or glass containers, or whether it was kept in room temperature, dark cabinet, or refrigerated environments.

3.3.3. Physical Observation of Palm Oil

Figure 11 shows changes in the physical properties of palm oil after 12 weeks of storage in different combinations of container types and environmental conditions. The codes A, P, and G represent aluminium, plastic, and glass containers, respectively, while the vertical arrangement from left to right shows storage conditions in refrigeration, cabinets, and room temperatures.

Visually, palm oil stored in refrigerated conditions changes to be murky with a paler orange colour compared to the initial red colour (Figure 10). In addition, an increase in viscosity was also observed in samples stored under these conditions. These changes are related to the crystallization process of saturated fatty acid fractions, especially palmisite and stearate, which have a relatively high melting point so they tend to form a semi-solid phase at low temperatures [21,22]. This phenomenon causes the formation of crystalline structures that increase the scattering of light and give the oil a cloudy appearance.

In contrast, palm oil stored at cabinet conditions and room temperature showed a relatively similar colour to the initial condition, without visually significant changes in viscosity. This indicates that although chemical degradation occurs as indicated by the increase in FFA values, the change has not been significant enough to affect the physical properties macroscopically.

These findings are also consistent with the results of the absorbance analysis, where the absorbance value of palm oil remains constant during storage. This suggests that the physical changes observed in refrigeration conditions are more caused by phase changes (crystallization) than by oxidative degradation. Thus, the physical properties of palm oil are greatly influenced by its fatty acid composition, in particular its high saturated fatty acid content, which determines the crystallization behaviour at low temperatures.

Figure 10. Initial colour of palm oil.

Figure 11. Palm oil after 12 weeks.

4. Discussions

4.1. Free Fatty Acid (FFA) Levels

In general, increased levels of free fatty acids (FFA) were observed in all types of oils during the storage period, indicating the occurrence of degradation through hydrolysis and lipid oxidation reactions. The results showed that plastic containers consistently produced the highest FFA values at the end of storage, regardless of environmental conditions. These findings indicate that the intrinsic properties of container materials play an important role in determining oil stability.

The semi-permeable properties of plastics to oxygen and water vapour allow for the diffusion of small molecules into the system, which can accelerate the hydrolysis and lipid oxidation reactions [8]. In addition, the possibility of condensation in refrigeration conditions can increase the contact of water with oil in plastic containers, thereby accelerating the formation of FFA through hydraulic mechanisms.

However, the results of this study also show that storage temperature remains a dominant factor in controlling the rate of degradation. In general, low temperature (refrigeration) conditions are able to inhibit the increase in FFA compared to room temperature, which is in line with previous reports that low temperatures decrease the rate of oxidation and hydrolysis reactions by reducing the kinetic energy of the system [12,13]. Therefore, oil stability is the result of the interaction between the material properties of the container and environmental conditions, with temperature as the main variable.

In sesame oil, the highest FFA values were observed in aluminium containers stored at room and cabinet temperature. This indicates the possible contribution of metallic materials to the acceleration of lipid oxidation through catalytic mechanisms [9,23]. The combination of high temperatures and the potential for metal catalytic activity can accelerate the formation of degradation products, including FFA.

Meanwhile, in palm oil, the highest FFA value was observed at room temperature, even in glass containers that were theoretically inert and non-permeable. This suggests that the influence of temperature can overcome the protective effects of container materials, especially under more extreme storage conditions. These findings are in line with previous studies that have shown that high temperatures are a major factor in accelerating oil degradation [24], although in some cases they contradict the assumption that inert containers always provide optimal protection [25].

4.2. Absorbance Value

The absorbance value indicates variations depending on the type of oil, storage conditions, and type of container. In soybean oil, a significant increase in absorbance was observed at room temperature conditions, especially in aluminium and plastic containers, indicating the formation of secondary oxidation products. This is consistent with the literature that states that increased absorbance is related to the formation of chromophore compounds due to lipid oxidation [16,26].

In contrast, the lowest absorbance values were consistently found in refrigeration conditions, which corroborated that low temperatures are able to inhibit the formation of oxidation products even in high-permeability containers such as plastics [12,27]. This reaffirms that temperature is the main factor in controlling the oxidative stability of oils.

Interestingly, in sesame oil, the highest absorbance value was observed in the refrigeration conditions, which seems to contradict the general theory. This phenomenon can be explained by the occurrence of partial crystallization at low temperatures, mainly due to the presence of fractions of saturated fatty acids such as palmitic and stearate. This crystallization leads to the formation of suspended solid particles that increase light scattering, resulting in increased absorbance values that do not fully reflect chemical oxidation [28,29].

Thus, in sesame oil, the increase in absorbance is not only affected by oxidation, but also by physical changes due to crystallization. This suggests that the interpretation of UV–Vis data needs to take into account the physical conditions of the sample, especially at low temperatures.

In palm oil, the absorbance value remains constant at 1,000 for the entire storage period. This is likely due to the high carotenoid content that dominates the absorbance spectrum at the 465 nm wavelength, so that small changes due to oxidation are not significantly detected. In addition, carotenoids also act as natural antioxidants that increase the oxidative stability of oils [20]. These findings show the limitations of the UV–Vis method at single wavelengths in detecting oxidative changes in oils with high pigment content.

4.3. Physical Observation

Changes in the physical properties of oils are generally consistent with the results of chemical analysis. In soybean oil, samples stored in refrigerated conditions showed relatively stable colours compared to the initial conditions, while at room and cabinet temperatures, colour darkening occurred. These changes are related to the oxidation process that produces coloured compounds and pigment degradation during storage [19].

In sesame oil and palm oil, storage under refrigerated conditions leads to the formation of semi-solid phases and cloudy appearance, which is accompanied by increased viscosity. This phenomenon is caused by the crystallization of saturated fatty acid fractions that have higher melting points, such as palmirate and stearate [21,22]. This suggests that the physical properties of the oil are greatly influenced by the lipid composition and storage temperature conditions.

Interestingly, visual changes are not always in line with the results of absorbance, especially in sesame oil. Although the absorbance value increases, the colour change is not always clearly detected by visual observation. This shows the limitations of human visual perception in detecting subtle colour changes, and confirms the importance of using instrumental methods such as UV-Vis for oil quality analysis [18].

4.4. Research Limitations

It should be noted that the FFA measurements in this study use the colorimetric test strip method which is semi-quantitative, so it does not allow inferential statistical analysis such as standard deviation calculations. In addition, each treatment condition has no replication, so the analysis is focused on trend-based analysis.

Nonetheless, this approach remains relevant to identify the direction of oil degradation comparatively. Further research is recommended using quantitative methods such as standard titration or chromatography as well as experimental design with replication to allow for more robust statistical analysis.

4.5. Future Research

Future research is recommended to expand the analytical depth and robustness of oil stability evaluation under varying storage conditions. The use of quantitative methods, such as titrimetric analysis for free fatty acids and advanced spectroscopic techniques including Fourier Transform Infrared (FTIR) spectroscopy, would enable more precise characterisation of chemical changes, particularly in functional groups associated with lipid oxidation.

In addition, future studies should incorporate replicated experimental designs to allow statistical analysis, including the calculation of uncertainty parameters such as standard deviation. This would improve the reliability and comparability of results across different storage conditions and oil types.

Further investigation into additional quality parameters, such as peroxide value, p-anisidine value, and volatile compound profiling, is also recommended to provide a more comprehensive understanding of primary and secondary oxidation processes. Moreover, the influence of microbial activity and potential bioactive properties, including antibacterial effects of oils under different storage conditions, may offer additional insights into oil preservation and safety.

Finally, expanding the range of oil types and packaging materials, including modern barrier materials and active packaging systems, would contribute to a more holistic evaluation of oil stability in real-world applications across food, nutraceutical, and bioenergy sectors.

5. Conclusions

This study demonstrated that storage temperature is the primary factor influencing the stability of soybean, sesame, and palm oils during storage. Refrigeration effectively suppressed the increase of FFA and absorbance across all oil types, while higher temperatures accelerated degradation, particularly in soybean oil due to its high unsaturation. Container material showed a secondary effect, where plastic tended to promote higher FFA formation, likely due to its permeability to oxygen and moisture, while glass provided better stability. Aluminium exhibited increased oxidation trends under certain conditions, suggesting possible catalytic interactions. Distinct behaviour was observed among oils. Sesame oil showed increased absorbance under refrigeration, likely influenced by crystallization effects, while palm oil maintained stable absorbance values, indicating higher oxidative stability despite observable physical changes. Overall, oil stability is governed by the interaction between storage temperature, container material, and intrinsic oil composition. Optimal preservation can be achieved through low-temperature storage combined with low-permeability containers.

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Declaration of Conflict of Interest

The authors declared no conflict of interest with any other party on the publication of the current work.

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