



Oxidative Stability and Shelf-Life Estimation of Virgin and Refined Coconut Oils during Storage: A Comparative Approach

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Abstract

The oxidative stability and shelf life of Virgin Coconut Oil (VCO) and Refined Coconut Oil (RCO) were evaluated under accelerated aging conditions at 60°C over a 12-week period. Key quality parameters, including free fatty acid (FFA) content, peroxide value (PV), p-anisidine value (p-AV), and induction time, were systematically monitored to assess the oils' degradation behavior. Results demonstrated that VCO exhibited superior oxidative stability, with a lower final FFA (1.72 g/100 g), PV (11.5 mEq O₂/kg), and p-AV (10.2) compared to RCO (1.87 g/100 g, 13.0 mEq O₂/kg, and 11.7, respectively). Furthermore, the induction time of VCO declined from 6.5 to 1.0 hours, whereas RCO exhibited a more rapid decrease from 4.2 to 0.6 hours. Regression analysis predicted that RCO reached the critical induction time threshold (1.5 hours) at approximately 7.9 weeks, while VCO maintained stability until around 10.3 weeks. The enhanced stability of VCO is attributed to the preservation of natural antioxidants, which are significantly diminished during the refining process. These findings highlight the critical role of minimal processing in prolonging coconut oil shelf life and suggest VCO as a preferable choice for applications requiring extended oxidative stability. Future research should validate these results under real storage conditions and optimize predictive models for shelf-life estimation.

Keywords: Virgin Coconut Oil; Refined Coconut Oil; Oxidative Stability; Shelf Life; Antioxidants

1. Introduction

The comparison between Virgin Coconut Oil (VCO) and Refined Coconut Oil (RCO) is essential for understanding their respective benefits, particularly regarding their oxidative stability and nutritional profile.

VCO is extracted through mechanical cold pressing, which enables it to retain beneficial bioactive compounds such as tocopherols and polyphenols. These compounds contribute to its noted antioxidant properties, which may enhance its shelf life and provide various health benefits, including anti-inflammatory effects (Vasconcelos et al., 2020; Khairati, 2023). Conversely, RCO undergoes a refining process, including bleaching and deodorization, aimed at improving sensory properties, which often results in a loss of many beneficial compounds, potentially compromising its oxidative stability and nutritional value (Ramya et al., 2022).

Oxidative stability is a critical factor in determining the shelf life of oils, as oils with low oxidative stability are more prone to spoilage, losing nutritional value and flavor. VCO is known to exhibit higher oxidative stability than RCO. This is due to its composition of medium-chain fatty acids (MCFAs), particularly lauric acid, which comprises about 53-54% of VCO's fatty acid content. The presence of lauric acid significantly enhances its oxidative stability, making VCO more stable during storage compared to RCO, which loses many protective compounds during the refining process (Khairati, 2023; Patil & Benjakul, 2020; Ajogun et al., 2020). Additionally, the higher levels of phenolic compounds in VCO not only bestow antioxidant properties but also help maintain oil quality over time, supporting its claimed superiority in oxidative stability (Briceño-Islas et al., 2023; Soo et al., 2020). Although the oxidative stability of VCO is well-established, empirical data directly comparing the oxidative stability of VCO and RCO under controlled storage conditions remains limited. While the stability of VCO has been proven in various contexts, its specific advantages over RCO under identical conditions require further investigation. Future research should focus on systematically exploring these differences, particularly through controlled shelf-life studies to more robustly substantiate claims surrounding the oxidative stability of VCO compared to RCO (Patil & Benjakul, 2020; Ajogun et al., 2020; Ayub et al., 2022).

This study presents a new approach in comparing the oxidative stability of VCO and RCO through accelerated aging tests under controlled storage conditions to uncover significant differences in the stability of these two types of coconut oil. The novelty of this research lies in its use of a more systematic method to measure shelf life and oxidative stability of coconut oils, which has been previously limited to more general parameters.

The primary aim of this study is to compare the oxidative stability and shelf life of VCO and RCO during storage under accelerated aging conditions. This study aims to explain the factors influencing the differences in stability between the two types of oils and provide a deeper understanding of the impact of the refining process on the shelf life of coconut oil. Based on the comparison of bioactive content and chemical composition of both types of coconut oil, the hypothesis of this research is that RCO will have reduced oxidative stability and a shorter shelf life compared to VCO, due to the loss of protective compounds during the refining process.

Previous studies have shown that oil refining, which includes processes such as bleaching and deodorization, can reduce the natural antioxidant compounds found in oils, a key factor influencing their oxidative stability. For instance, Vasconcelos et al. demonstrate that VCO retains more bioactive components such as polyphenols and tocotrienols compared to RCO, which undergoes bleaching and deodorization processes that strip many of these beneficial compounds away (Vasconcelos et al., 2020). These antioxidants play a crucial role in combating oxidative deterioration, which is more pronounced in unsaturated fats found in oils (Anjali et al., 2023). When examining the oxidative stability of oils, it is recognized that oils high in unsaturated fatty acids are more susceptible to oxidation, leading to rancidity and thus a shorter shelf life (Ramya et al., 2022).

Moreover, studies have shown that lower moisture content correlates positively with the shelf life of oils because moisture is a catalyst for hydrolysis and subsequent rancidity (Perera et al., 2020). The proper maintenance of low moisture levels is critical during storage, as cited in research indicating that VCO tends to maintain optimal moisture levels, thereby aiding in their longevity compared to their refined counterparts, where processing may not effectively manage this attribute (Hussain et al., 2020). The physicochemical properties of both oil types further provide insights into their stability. For instance, Maurikaa et al. conducted comparative studies evaluating VCO and RCO based on various parameters like moisture content, saponification value, and free fatty acid levels. Their findings suggest that VCO generally exhibits favorable attributes conducive to a longer shelf life (Karunasiri et al., 2020). In contrast, refining tends to elevate the

acidity levels, which could correlate with a diminished shelf life (Martín-Torres et al., 2022).

2. Research Methods

This section describes the materials, experimental design, and methods used to collect and analyze data regarding the oxidative stability and shelf life of Virgin Coconut Oil (VCO) and Refined Coconut Oil (RCO) under accelerated aging conditions.

2.1. Materials and Experimental Design

Oil Samples

The Virgin Coconut Oil (VCO) and Refined Coconut Oil (RCO) samples used in this study were obtained from a reputable supplier. Both oils were sourced from mature coconut kernels and stored in dark glass bottles to minimize oxidation due to light exposure. This storage method is supported by literature, which suggests that oils should be stored in opaque containers to limit light penetration, thus preserving their antioxidant properties and extending their shelf life (Perera et al., 2020). Light exposure accelerates photodegradation, promoting oxidative rancidity, and this precaution helps mitigate such risks (Thanaruenin et al., 2022).

2.2 Experimental Setup

The oils were stored at a constant temperature of 60°C in a temperature-controlled oven for 12 weeks, which mirrors accelerated aging conditions commonly used to simulate long-term storage and evaluate the oxidative stability of oils (Thanaruenin et al., 2022). Storage at elevated temperatures accelerates oxidative degradation, as high temperatures exacerbate the breakdown of fats by promoting the formation of peroxides and free fatty acids (FFA), which reflect the degree of rancidity (Perera et al., 2020). The oils were sampled at regular intervals, typically every two weeks, to assess changes in oxidative stability and monitor any degradation in quality, similar to methods used in previous studies (Dedebaş et al., 2020).

2.3. Quality Indices and Analytical Methods

Free Fatty Acids (FFA)

The FFA content of the oils was measured to track hydrolysis during the storage period. This method is widely used to assess oxidative rancidity, where hydrolytic reactions convert triglycerides into free fatty acids (Tan et al., 2023). The FFA content was quantified by titration using an alcohol solution, with the results expressed in grams of oleic acid per 100 grams of oil, following the standard acid-base titration technique for edible oils (Lu et al., 2024). This method provides an accurate reflection of oxidative degradation in oils, as higher levels of FFA indicate increased rancidity (Kim & Hwang, 2024). The titration method was chosen because it is commonly used in food quality control standards to evaluate the freshness and stability of oils (Preez et al., 2022).

Peroxide Value (PV)

Peroxide Value (PV) was used to measure primary oxidation products (hydroperoxides) formed during the storage period. PV is one of the most commonly used methods to assess the oxidative stability of oils (Ivanova et al., 2025). The iodine-based iodometric method was employed, which involves titrating the active oxygen present in the oil by reacting it with iodide, then quantifying the iodine released through sodium thiosulfate titration (Hafer et al., 2020). This method is standard in the industry and is highly reproducible, making it suitable for continuous monitoring of oil degradation (Romano et al., 2021).

p-Anisidine Value (p-AV)

The p-Anisidine Value (p-AV) was measured to evaluate secondary oxidation products, which are formed after the initial oxidation phase. p-AV quantifies aldehydes and other volatile compounds resulting from lipid oxidation, which are associated with the development of off-flavors and rancidity (Chen et al., 2024). The procedure involved reacting the oil with p-anisidine in glacial acetic acid and measuring absorbance at 350 nm, as recommended by industry standards for assessing oxidative deterioration (Saragih et al., 2023). p-AV is crucial for evaluating the sensory quality of oils, as higher p-AV levels correlate with an increase in aldehydes and ketones that affect taste and aroma (Lee et al., 2021; Untea et al., 2021).

Induction Time (Rancimat Method)

The oxidative stability of the oils was measured using the Rancimat method (ISO 6886:2016), which evaluates the time taken for a significant increase in conductivity, indicating the onset of oxidation. The Rancimat test is widely accepted in the oil industry for measuring the oxidative stability of oils at high temperatures (Symoniuk et al., 2022). The samples were heated at 120°C, and the induction time was recorded to correlate with shelf life predictions. The Rancimat test is particularly effective in accelerated aging studies, where higher temperatures (100-120°C) simulate long-term storage conditions (Gagour et al., 2022). This method is advantageous because it offers rapid results and is less labor-intensive compared to traditional methods like PV or p-AV, making it ideal for routine quality control (Zieniuk et al., 2021).

2.4. Shelf-Life Prediction

Extrapolation Method

The shelf life of the oils was predicted by extrapolating the induction time from accelerated aging conditions (373-403K) to the storage temperature of 25°C (room temperature). This method is commonly used to simulate long-term storage and predict the shelf life of oils (Gagour et al., 2022). The relationship between the Rancimat induction time at elevated temperatures and the shelf life at room temperature follows an Arrhenian model, which allows for the estimation of the oil's oxidative stability over time based on its behavior under accelerated aging conditions (Gagour et al., 2022). This method provides an effective way to predict the longevity of oils when stored under normal conditions, with previous studies showing that a few days of testing at higher temperatures can be equivalent to a year of shelf life under room temperature (Alshehawy et al., 2021).

3. Results and Discussion

3.1. Free Fatty Acid (FFA) Content

The FFA content of both Virgin Coconut Oil (VCO) and Refined Coconut Oil (RCO) exhibited a steady increase throughout the 12-week storage period. Initially, VCO showed a lower FFA value (0.75 g/100g) compared to RCO (0.88 g/100g), indicating its superior initial quality due to minimal processing. By the end of the storage period, VCO's FFA reached 1.72 g/100g, while RCO recorded a higher value of 1.87 g/100g (Figure 1).

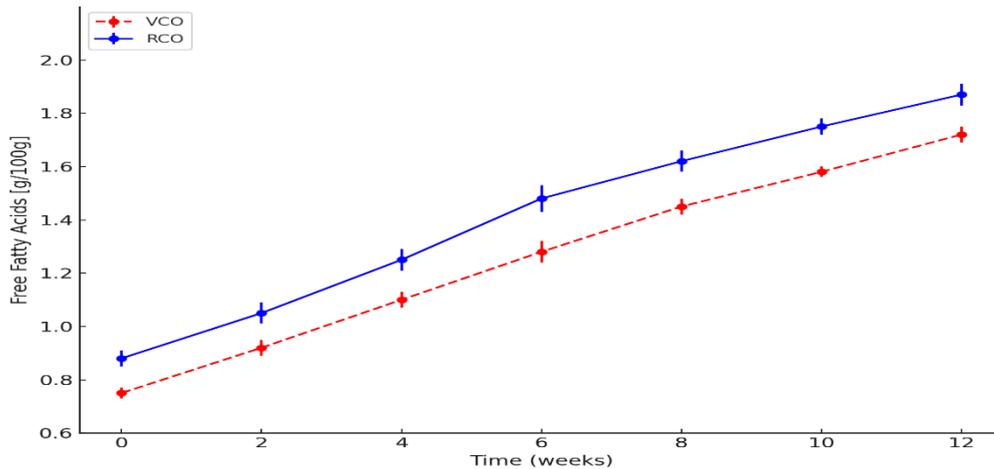


Figure 1: Free Fatty Acids of VCO and RCO

Both oils exhibited a steady increase in FFA, with VCO showing a slower rate of increase compared to RCO. This result is consistent with the literature, which suggests that moisture and temperature are key factors influencing the formation of FFAs in oils (Widari et al., 2021). Hydrolysis, the process through which triglycerides break down into FFAs, occurs more rapidly in the presence of moisture, which was present in both VCO and RCO. Higher temperatures, particularly those used in this study (60°C), accelerate this process, further increasing FFA levels (Zhang et al., 2023). The slower increase in FFA in VCO compared to RCO can be attributed to its higher content of natural antioxidants, which may help mitigate the effects of hydrolysis and oxidative degradation (Zhang et al., 2023). The slower increase in FFA in VCO suggests that its antioxidant compounds, which are retained due to minimal processing, may offer better protection against hydrolysis and oxidation compared to RCO, which loses many of these bioactive compounds during refining. This finding aligns with literature that suggests higher levels of antioxidants in virgin oils contribute to better oxidative stability, even though higher FFA levels in VCO can be indicative of reduced oxidative stability (Zhang et al., 2023; Perera et al., 2020).

3.2. Primary Oxidation Products (Peroxide Value)

Peroxide Value, an indicator of primary oxidation products (hydroperoxides), progressively increased for both VCO and RCO during storage. Initially, PV for VCO was 2.9 mEq O₂/kg, slightly lower than RCO's 3.2 mEq O₂/kg. After 12 weeks, VCO reached a PV of 11.5 mEq O₂/kg, whereas RCO peaked at 13.0 mEq O₂/kg (Figure 2).

The increase in PV for both VCO and RCO over the 12-week storage period is consistent with previous studies, which indicate that PV serves as a critical indicator of oxidative degradation in oils, reflecting the concentration of hydroperoxides—the primary products of lipid oxidation (Sanna & Fadda, 2025; Tsitlakidou et al., 2024). Hydroperoxides are early markers of fat oxidation, and their formation signifies the onset of rancidity in oils, which, over time, can lead to a deterioration of the oil's sensory and nutritional properties (Yu et al., 2022). The results show a significantly faster increase in PV for VCO compared to RCO, indicating

that VCO is more susceptible to oxidative degradation during storage.

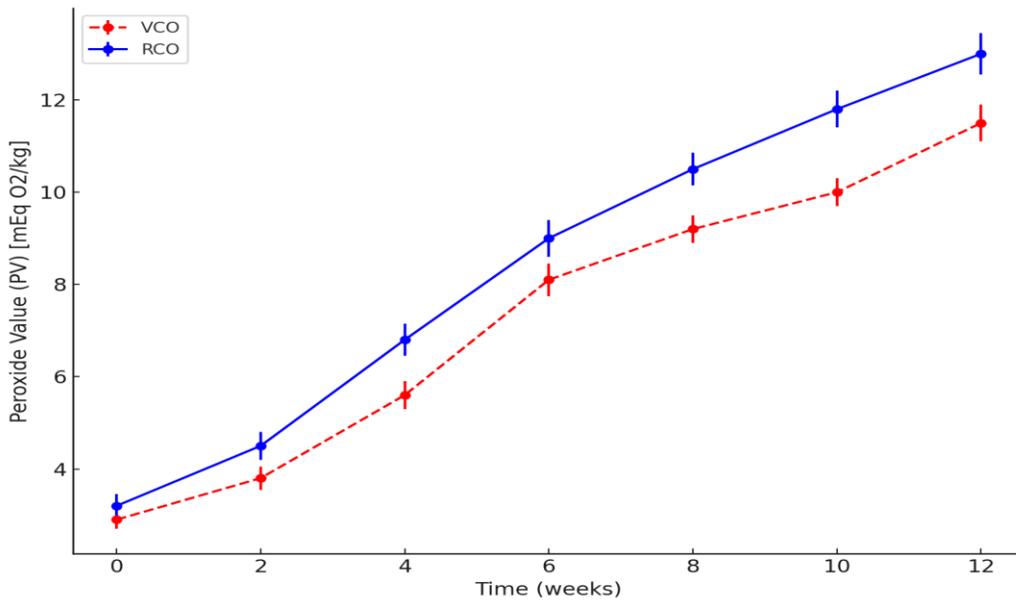


Figure 2: Peroxide Value of VCO and RCO

This is particularly noteworthy given that VCO typically contains higher concentrations of polyunsaturated fatty acids (PUFAs), which are more prone to oxidation than the saturated fats found in RCO (Martin-Rubio et al., 2020). In contrast, RCO, being refined and processed, exhibits slower oxidation due to the removal of unstable compounds, such as antioxidants, during the refining process (Mezni et al., 2023). The higher PV observed in VCO is in line with studies that have shown that virgin oils, rich in PUFAs, generally exhibit greater increases in PV over time, leading to rapid deterioration relative to refined oils, which are more stable due to the reduction of reactive compounds during processing (Martin-Rubio et al., 2020). Higher PV values in VCO, as seen in this study, correlate with increased risks for rancidity and off-flavors, which significantly impact consumer acceptance, even at earlier stages of storage (Özcan et al., 2021).

These findings further emphasize the importance of monitoring PV as an essential quality control measure in the oil industry, as it directly relates to oil shelf life and oxidative stability (Saleh, 2020). In practical terms, the observed PV increase in VCO suggests that careful storage conditions, such as keeping oils at lower temperatures and minimizing exposure to light and oxygen, are crucial to maintaining their quality. As noted by Zhang et al. (2023), higher storage temperatures accelerate the formation of peroxides, which supports the findings of this study showing a more rapid increase in PV at 60°C. Moreover, the study's results align with earlier research indicating that refined oils, such as RCO, exhibit lower initial PV values and slower oxidation rates due to the refining process, which effectively removes many of the compounds responsible for oxidative degradation (Gürdil et al., 2020). This finding is significant for consumers and manufacturers as it points to the enhanced stability of refined oils under conditions that may otherwise promote the oxidation of virgin oils.

3.3. Secondary Oxidation Products (p-AV)

The p-AV values, representing secondary oxidation products such as aldehydes and ketones, also displayed an upward trend during storage. VCO's p-AV increased from 3.4 to 10.2, while RCO's p-AV rose more sharply from 3.7 to 11.7 (Figure 3).

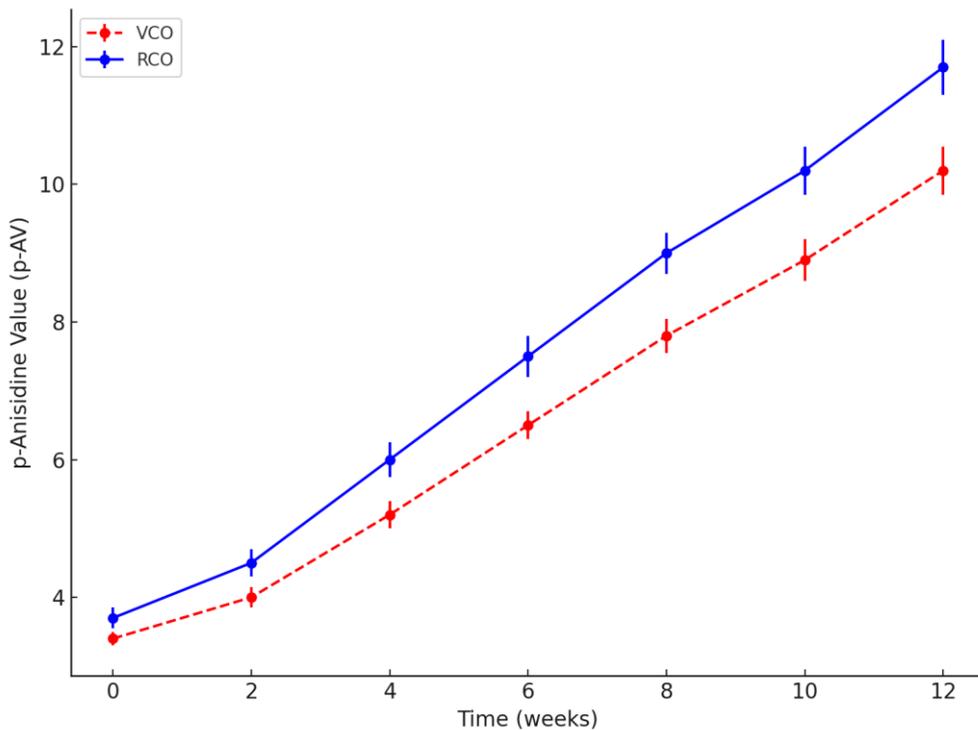


Figure 3: p-Anisidine of VCO and RCO

The increase in p-AV for both VCO and RCO during storage is a clear indicator of secondary oxidation products, primarily aldehydes and ketones, which are formed from the breakdown of hydroperoxides. The rise in p-AV reflects the ongoing oxidative degradation that affects the sensory and nutritional quality of oils (Sourki et al., 2021; Mudrić et al., 2020). According to the literature, p-AV is not just a reflection of peroxide concentrations, but a broader measure of oxidative degradation, capturing byproducts that accumulate over time during lipid peroxidation (Sourki et al., 2021).

VCO shows a slower increase in p-AV, with a significant rise occurring after the 4th week of storage. This slower accumulation of secondary oxidation products can be attributed to the higher antioxidant content in VCO, which is preserved due to minimal processing (Putra et al., 2022). Antioxidants, such as tocopherols and polyphenols, present in VCO help delay the formation of aldehydes and ketones, thus slowing the increase in p-AV. As noted by Chen et al. (2024), antioxidants play a crucial role in preventing the breakdown of hydroperoxides into secondary oxidation products, which is essential for maintaining the sensory quality of oils over time.

Similarly, RCO experiences a sharp increase in p-AV, reaching its peak value by the 12th week. The refining process, which includes bleaching and deodorization, removes most of the oil's natural antioxidants, making it more susceptible to secondary oxidation (Kampa et al., 2022). This is consistent with the findings of Martin-Rubio et al. (2020), which reported that refined oils tend to accumulate secondary oxidation products more quickly because the removal of antioxidants during processing reduces their ability to prevent the formation of aldehydes and other degradation products. The higher p-AV values in RCO indicate that the absence of antioxidants accelerates the oxidation process, leading to rancidity and undesirable flavors, which are reflected in the sensory degradation of the oil.

The significant increase in p-AV for RCO aligns with previous research showing that refining reduces antioxidant content, which directly impacts the formation of secondary oxidation products (Lucci et al., 2020;

Harzalli et al., 2022). The absence of natural antioxidants in RCO allows for uncontrolled oxidation, leading to higher levels of aldehydes and ketones, which significantly affect the sensory properties of the oil, resulting in rancid or unpleasant flavors (Kampa et al., 2022).

Sensory evaluation of the oils also confirms that higher p-AV values correlate with negative changes in taste and aroma, which are common indicators of rancidity. Studies have shown that oils with higher p-AV values are typically less preferred by consumers due to the development of unpleasant tastes and odors (Lee & Ju, 2024; Juhaimi et al., 2024). Therefore, the observed increase in p-AV in both oils reflects the progression towards oxidation, and the difference between VCO and RCO highlights the impact of processing on oil stability.

3.4. Rancimat Test Results

Induction Time (IT) declined consistently for both VCO and RCO, indicating the deterioration of oxidative stability over time. VCO maintained a higher induction time across all observation points, starting at 6.5 hours and decreasing to 1.0 hour by Week 12. RCO exhibited a faster decline, starting at 4.2 hours and dropping to 0.6 hours (Figure 4).

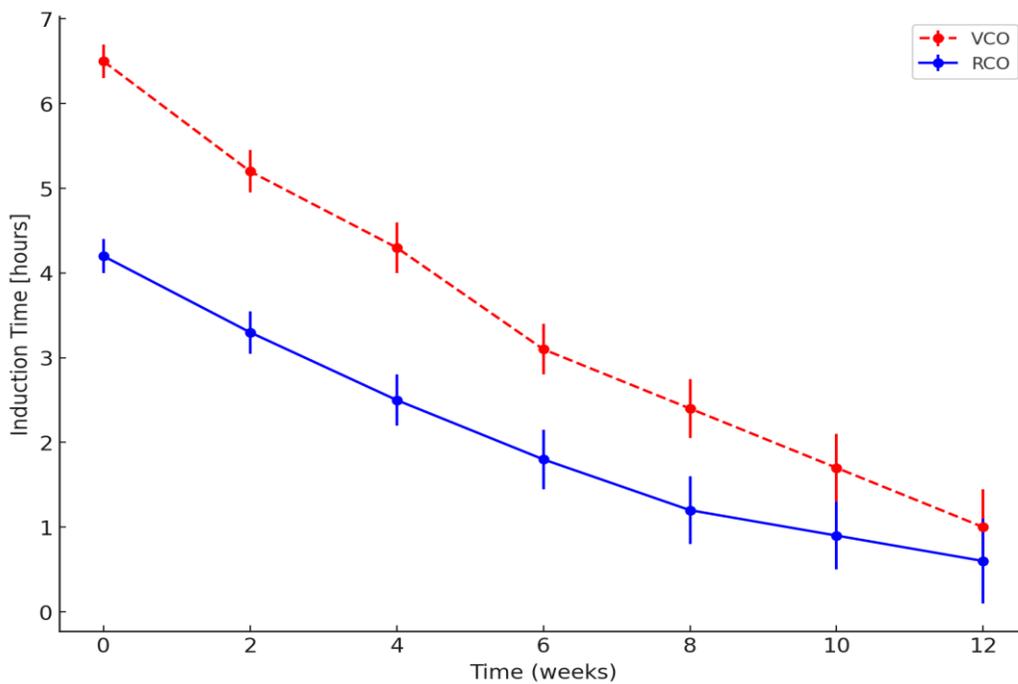


Figure 4: Induction Time of VCO and RCO

The reduction in induction time (IT) for both VCO and RCO over the 12-week storage period is a direct indication of the oils' decreasing oxidative stability, as measured by the Rancimat method. The induction time in the Rancimat test reflects the duration before the noticeable increase in conductivity, signifying the onset of oxidation due to the formation of volatile carboxylic acids (Devitasari et al., 2022; Aissa et al., 2023; Symoniuk et al., 2022). The observed decrease in induction time for both oils suggests that as oxidation progresses, the oils' resistance to oxidation diminishes, leading to quicker degradation. The initial higher induction time for VCO compared to RCO is in line with the literature, which indicates that VCO, due to its higher content of antioxidants and bioactive compounds, such as polyphenols and tocopherols, tends to exhibit greater resistance to oxidation (Putra et al., 2022). These natural antioxidants in VCO delay the onset of

oxidation, thus resulting in a longer induction time when compared to RCO, which undergoes a refining process that depletes these protective compounds (Flores & Camacho, 2024). As noted in previous studies, refining reduces antioxidant content, which makes refined oils, like RCO, more susceptible to faster oxidative degradation (Sampson, 2020; Grdil et al., 2020). Furthermore, the decrease in induction time observed in both VCO and RCO after 12 weeks of storage aligns with findings from the literature that high temperatures accelerate the oxidative degradation process, leading to a significant decrease in induction time (Symoniuk et al., 2022; Pei et al., 2022). As storage temperature increases, oxidation rates also increase, as evidenced by the faster reduction in IT in both oils when exposed to elevated temperatures during the Rancimat test (Symoniuk et al., 2022; Lu et al., 2021). This finding is consistent with research showing that elevated temperatures shorten the induction time in oils by accelerating lipid peroxidation and oxidation processes (Hamed et al., 2023). The significant difference in induction time between VCO and RCO supports the understanding that virgin coconut oil retains more natural antioxidants, providing it with superior oxidative stability when compared to refined oils (Jermwongruttanachai et al., 2021). The faster decrease in IT for RCO highlights the effect of refining on the oxidative stability of coconut oil, making it more vulnerable to oxidative reactions, particularly under elevated temperatures (Pei et al., 2022). These findings align with earlier studies that have demonstrated refined oils tend to exhibit shorter induction times, reflecting their decreased resistance to oxidation (Flores & Camacho, 2024; Pei et al., 2022).

The Rancimat test proves to be a valuable tool for predicting the oxidative stability and shelf life of oils. The predicted shelf life results are presented in Figure 5.

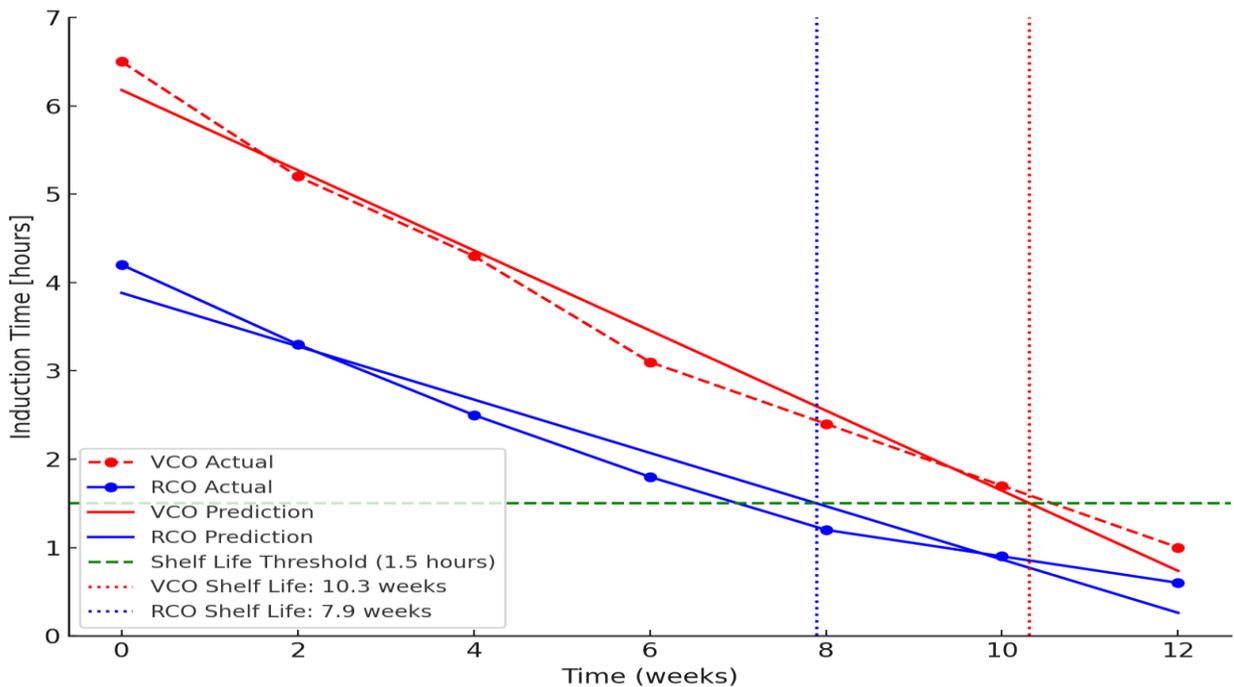


Figure 5: Induction Time-Shelf life of VCO and RCO

Based on the prediction model results, Virgin Coconut Oil (VCO) shows a longer shelf life compared to Refined Coconut Oil (RCO) when stored at high temperatures over a 12-week period. The linear regression model built from the Induction Time data indicates that VCO reaches the critical shelf life limit (Induction Time = 1.5 hours) at week 10.3 (~72 days), while RCO reaches it faster at week 7.9 (~55 days). The results obtained in this study emphasize the importance of protective antioxidants in virgin oils, which significantly extend the induction time and thus improve oxidative stability. For refined oils, the absence of these antioxidants contributes to a shorter induction time, which indicates faster oxidation and reduced shelf life (Symoniuk et al., 2022; Zahran & Najafi, 2020). Therefore, Rancimat induction time is an important parameter for assessing

the long-term usability of oils in both culinary applications and industrial uses (Guillén-Sánchez & Paucar-Menacho, 2020; Oancea et al., 2022).

The faster decrease in Induction Time in RCO suggests that the refining process contributes to the loss of bioactive compounds and natural antioxidants such as tocopherols and polyphenols, which play a crucial role in maintaining the oxidative stability of the oil. In contrast, VCO retains these components, providing protection against oxidative degradation during storage. These findings align with the literature, which states that oils with higher natural antioxidant content exhibit better oxidative resistance, slowing the accumulation of oxidation products such as FFA, PV, and p-AV. Therefore, the shelf life of coconut oil is practically highly dependent on its internal antioxidant content and the level of refining applied.

4. Conclusion

This study demonstrated the significant differences in oxidative stability and shelf life between Virgin Coconut Oil (VCO) and Refined Coconut Oil (RCO) under accelerated aging conditions. VCO exhibited superior oxidative stability compared to RCO, primarily due to its higher antioxidant content and natural bioactive compounds, such as tocopherols and polyphenols, which are removed during the refining process. The results showed that VCO maintained lower levels of oxidative products like free fatty acids (FFA), peroxide value (PV), and p-anisidine value (p-AV) over time, while RCO experienced faster degradation. The Rancimat test further supported these findings, with VCO showing longer induction times, indicating better resistance to oxidation. These results highlight the importance of refining processes and the impact they have on the oil's oxidative stability and shelf life. Given the superior stability of VCO, it is recommended that efforts be made to retain antioxidants during the refining process, or that RCO be stored and packaged more carefully to prevent premature degradation. Further studies are needed to explore alternative refining methods and environmental factors influencing coconut oil stability.

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Declaration of Conflicting Interests

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