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RESEARCH ARTICLE

Ultrasound-assisted deep eutectic solvent (DES) extraction of coconut dregs as a natural antioxidant to improve the chemical quality and stability of coconut oil

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ABSTRACT

Coconut dregs (CD), a by-product produced from the coconut milk industry, are high in antioxidant compounds and have the potential to act as a natural antioxidant. It can be considered as an alternative to synthetic antioxidants in the food industry. This research aimed to determine the total phenolic and total flavonoid content of coconut dregs extract using deep eutectic solvents (DES) as a green extraction method and to analyse the stability of coconut oil incorporated with different concentrations of coconut dregs extract during storage. The antioxidant properties of the CD extract were studied for total phenolic content (TPC), total flavonoid content (TFC), and 1,1-diphenyl-2-picrylhydrazyl (DPPH) scavenging capacity. The CD extract exhibited a TPC of 44.259 ± 0.059 mg GAE/g ($p < 0.05$), a TFC of 24.211 ± 0.469 mg QE/g ($p < 0.05$), and a DPPH scavenging activity of 77.15 ± 1.58% ($p < 0.05$). The oxidative stability of coconut oil was assessed through peroxide value (PV), p-anisidine value (AV), and thiobarbituric acid reactive substances (TBARS). In this study, the results showed that untreated coconut oil exhibited the highest PV (6.75 meqO_2/kg), AV (4.18), and TBARS (1.54 MDA eq/kg) at day 15, indicating advanced oxidation. In contrast, oils treated with CD extracted at 5% and 10% concentrations recorded significantly lower values, with 10% CD extract achieving PV, AV, and TBARS levels of 3.75, 2.62, and 0.83, respectively ($p < 0.05$). These results indicate that the CD extract was comparable to the synthetic antioxidant BHT, highlighting its efficacy in reducing oxidative degradation.

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1. INTRODUCTION

Coconut (*Cocos nucifera* L.) is a widely cultivated tropical plant. It is valued for its fruit, which is extensively used in food, nutraceutical, and cosmetic industries. One of the major by-products of coconut milk and oil extraction is coconut dregs, a fibrous residue typically discarded as waste. However, coconut dregs are increasingly recognised for their abundance of bioactive compounds, particularly polyphenols and flavonoids, which exhibit strong antioxidant properties (Abbasiliasi et al., 2019; Smith et al., 2015). The valorisation of such agro-industrial residues aligns with sustainable development goals and circular bioeconomy models by turning waste into high-value ingredients.

Coconut oil, while widely consumed, is prone to oxidative deterioration, especially under thermal or prolonged storage conditions. Lipid oxidation compromises oil quality, generating off-flavours and potentially toxic compounds. Traditionally, synthetic antioxidants such as butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA) have been used to mitigate oxidation. However, their potential carcinogenic and endocrine-disrupting effects have prompted growing demand for natural antioxidants that are safe, effective, and sustainable (List, 2016).

Conventional extraction of antioxidants from plant materials often involves organic solvents such as methanol, ethanol, or acetone. While effective, these solvents are related to environmental and health hazards, flammability, and high disposal costs. In recent years, natural deep eutectic solvents (NADES) have emerged as a promising green and sustainable alternative for extracting bioactive compounds. These solvents are formed through the interaction between a hydrogen bond donor (HBD) and a hydrogen bond acceptor (HBA), resulting in a eutectic mixture stabilised by strong hydrogen bonding (Cui et al., 2018). This interaction significantly lowers the melting point of the mixture, making NADES particularly suitable for extracting thermolabile compounds without degradation (Oomen et al., 2020; Fuad et al., 2021; Zhou et al., 2024). Despite these advantages, NADES possibly have one limitation, which is that their high viscosity may restrict the mass transfer during the extraction process (Hu et al., 2023).

Recent literature highlights the advantages of NADES over conventional solvents, including non-toxicity, biodegradability, customisable polarity, and cost-effectiveness (Hernández-Corroto et al., 2020). NADES show particular affinity for polar bioactives like phenolic acids and flavonoids, and when combined with ultrasound-assisted extraction (UAE), they enhance mass transfer, disrupt cell structures, and preserve heat-sensitive compounds (Sayem et al., 2024). They are also Generally Recognized As Safe (GRAS), making them interesting to be extended in food and nutraceutical applications.

Notably, deep eutectic solvents (DES) have demonstrated superior performance in extracting polyphenols from various plant by-products such as pomegranate peel, grape pomace, olive fruit dregs, and green tea waste (Hernández-Corroto et al., 2020; Arief et al., 2023). The use of choline chloride-lactic acid-based DES has been shown to increase extraction yield, antioxidant capacity, and stability of phenolic-rich extracts while reducing environmental impact. Moreover, findings showed that NADES based on choline chloride and propylene glycol had exhibited significant antimicrobial activity from rosemary extract (Wojeicchowski et al., 2021). However, despite their potential, limited studies have applied DES to extract antioxidants from coconut dregs, and even fewer have explored their efficacy in real food systems such as edible oils.

Thus, this research gap is addressed by extracting antioxidant compounds from coconut dregs using a green DES-based extraction method combined with ultrasound assistance and evaluating the antioxidant efficacy of the resulting extract in enhancing the oxidative stability of coconut oil during storage. This investigation not only supports sustainable waste valorisation but also contributes to the growing body of research on DES as a practical tool for natural antioxidant extraction in the food industry.

2. MATERIALS AND METHODS

2.1. Chemicals and Materials

For the material, 1.5 kg of coconut dregs were obtained from a coconut milk local stall in Terengganu, Malaysia. The coconut oil was purchased from an online store and stored at room temperature until use. The chemical reagents used included choline chloride, lactic acid, methanol, reagent Folin-Ciocalteu, gallic acid, sodium nitrite ($NaNO_2$), aluminum chloride ($AlCl_3$), sodium hydroxide (NaOH), quercetin, diphenyl picryl-hydrazyl (DPPH), ascorbic acid, butylated hydroxytoluene (BHT), thiobarbituric acid (TBA), isooctane, p-anisidine, glacial acetic acid, chloroform, potassium iodide, starch and sodium thiosulphate. All solvents and reagents were of analytical grade.

2.2. Preparation of the coconut dregs extract

For this experiment, 500 g of coconut dregs were dried at 50 °C for 24 hours, ground, and sieved (220 µm). Samples were stored in glass jars with silica gel. The DES solvent was prepared by heating choline chloride (Sigma, USA) and lactic acid at 80 °C for 2 hours, then at 50 °C until clear. As for the phenolic compounds, they were extracted via ultrasound-assisted extraction. First, 20 g of dried coconut powder was mixed with 150 mL DES in an ultrasonic bath (Hwashin, Korea) (37 kHz, 50 W) at 25 °C for 40 min, followed by centrifugation (5810/5810R, Germany) (6000 rpm, 5 min) and filtration (Hernández-Corroto et al., 2020).

2.3. Total phenolics content (TPC) direct measurement

This method is based on measuring several aromatic benzene rings in gallic acid at 280 nm, where their characteristic UV absorbance allows sensitive detection of phenolic structures. A calibration curve for gallic acid was constructed and used as a standard curve. The total phenol in coconut dregs extract was detected at 280 nm and calculated using the gallic acid calibration curve, represented as mg/L gallic acid equivalent (GAE280). The analysis was carried out in triplicate

2.4. Total flavonoid content (TFC)

In here, 1 mL of sample was mixed with 0.3 mL of 5% $NaNO_2$ (R&M, UK) and incubated for 5 minutes, followed by 0.3 mL of 10% $AlCl_3$ and swirling for 6 minutes. After neutralisation with 2 mL of 1M NaOH, absorbance was measured at 517 nm using a UV-Visible spectrophotometer (UV-1900 Shimadzu, Japan). A standard curve was prepared with 0–50 mg/L quercetin (Marsoul et al., 2020).

2.5. 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay

In this stage, 1300 µL of 0.004% DPPH (Aldrich, USA) in methanol was mixed with 100 µL of extract solution or methanol (negative control). After 30 minutes of incubation in the dark at room temperature, absorbance was measured at 517 nm. Ascorbic acid served as a positive control, and tests were performed in triplicate (Marsoul et al., 2020).

2.6. Preparation of coconut oil with coconut dregs extracts

Coconut oil was mixed with 20 mg of butylated hydroxytoluene (BHT) (Aldrich, Germany) or coconut dregs extract (CD) at 1%, 5%, and 10% concentrations per 100 g of oil. The mixture was blended using an Ultra Turrax homogenizer (IKA T25, USA), whereby each mixture was blended for 2 minutes at 15,000 rpm at room temperature (Moczkowska et al., 2020).

2.7. Oxidation process

The oxidation process was conducted by storing 80 mL oil samples in 250 mL amber bottles at 60 °C, with and without antioxidants (control, 1% CD, 5% CD, 10% CD, or BHT). Chemical analysis was performed on days 0, 1, 4, 8, 11, and 15 (Moczkowska et al., 2020).

2.8. Thiobarbituric acid reactive substance (TBARS)

During this stage, 1 g of oil was mixed with 5 mL of glacial acetic acid and shaken at 70 rpm for 30 minutes. Then, 1 mL of the mixture was combined with 1 mL of 4 mM TBA (Sigma-Aldrich, USA) in glacial acetic acid and heated at 95 °C for 60 minutes. After cooling, absorbance was measured at 532 nm using a UV-VIS spectrophotometer (UV-1900 Shimadzu, Japan). A blank sample with acetic acid replaced the oil. The results were expressed as µmol TBARS/g oil (Moczkowska et al., 2020).

2.9. ρ-Anisidine value (AV)

During this process, 1 mL of coconut oil was dissolved in 25 mL of isooctane (Solution A). Then, 5 mL of Solution A was mixed with 1 mL of 0.25% p-anisidine in glacial acetic acid (Solution B). For reference, 5 mL of isooctane was mixed with 1 mL of 2.5 g/L p-anisidine in glacial acetic acid. Absorbance was measured at 350 nm using a UV-VIS spectrophotometer (UV-1900 Shimadzu, Japan) (Patil et al., 2020).

2.10. Peroxide value (PV)

To find the PV value, 2 g of the oil sample was dissolved in 10 mL of chloroform and 15 mL of glacial acetic acid. After adding 0.5 mL saturated potassium iodide (R&M, UK), the mixture was incubated in the dark for 5 minutes. Then, 75 mL of distilled water and 3 mL of 1% starch solution were added. The mixture was titrated with 0.01 M sodium thiosulfate (R&M, UK) until colourless. The Peroxide Value was calculated and expressed in mEq O_2/kg oil (Moczkowska et al., 2020).

2.11. Total Oxidation (TOTOX) Index

The Totox index is a measure used to assess the overall oxidation and quality of fats and oils. It combines the values of primary and secondary oxidation products to give a single comprehensive indicator. The Totox index is calculated by the formula AV + 2PV to indicate an oil's overall oxidation state (De Abreu et al., 2010).

2.12. Statistical analysis

Antioxidant activity and physicochemical properties of the oil (analysed in triplicate) were evaluated using Minitab software (version 15). Statistical differences among groups were determined through one-way ANOVA, with data normality verified using the kurtosis test. Tukey's post hoc test was applied to identify significant differences between groups at a significance level of $p < 0.05$).

3. RESULT AND DISCUSSION

3.1 Antioxidant assays

Table 1 presents the analysis of antioxidant activity, total phenolic content (TPC), total flavonoid content (TFC), and the free radical scavenging activity (DPPH) of the coconut dregs extract.

Table 1. Antioxidant properties of coconut dregs extract

Antioxidant Property	Coconut dregs extract
Total phenolic content (TPC) [mg GAE/g DM]	44.259±0.059
Total flavonoid content (TFC) [mg QE/g DM]	24.211±0.469
DPPH inhibitory effect [%]	77.150±1.580

The values are expressed as means±standard deviation for triplicate (n=3) analyses

Total phenolic content (TPC) is determined by looking at quantitative data on antioxidant potential compounds. The TPC of coconut dregs extract was 44.259 ± 0.059 mg GAE/g, indicating a high phenolic content with strong antioxidant potential. This value surpasses the 30.36 ± 1.07 mg GAE/g reported by Smith et al. (2015), highlighting the efficiency of ultrasound-assisted extraction (UAE) with DES over traditional methanol extraction, which suffers from passive diffusion and thermal degradation at high temperatures (170°C, 2 hours). UAE enhances phenolic recovery by disrupting cell walls at lower temperatures, preserving thermolabile compounds (Sayem et al., 2024), ultimately leading to the extraction of more stable, potent antioxidant constituents compared to conventional thermal methods.

The TPC value in this study aligns with previous reports on black sesame seed dregs, where fermented dregs (55.64 ± 4.06 mg GAE/100 mg) showed higher phenolic content than raw seeds (39.92 ± 4.14 mg GAE/100 mg) and seed dregs (25.68 ± 8.79 mg GAE/100 mg) (Rosni et al., 2024). While fermentation was not applied, the naturally high phenolic content in coconut may explain the observed TPC. However, the value remains lower than that of other by-products, such as green tea dregs, which range from 331.17 to 678.59 mg GAE/g due to their high catechin and tannin content (Arief et al., 2023). The TPC of green tea dregs might also be affected by extraction time and temperature, which results in lower phenolic content. One previous study showed

that the decrease in antioxidant activity of green tea according to storage temperature and time was due to the decrease in catechin contents (Kim et al., 2020). Increasing the solid-to-liquid ratio may also significantly improve total phenolic content (TPC) and antioxidant activity in 2,2-azinobis(3-ethylbenzthiazoline-6-sulphonic acid) (ABTS) and Ferric Reducing Antioxidant Power (FRAP) assays. However, beyond a certain ratio, TPC tends to decrease due to system saturation and potentially fewer available hydrogen bonds in the NADES (de Lima et al., 2024).

The TFC of coconut dregs extract in the present study was 24.211 ± 0.469 mg QE/g, significantly higher than the 5.78 ± 0.31 mg CE/g reported in the past study (Smith et al., 2015). This result highlights the efficiency of UAE with DES over traditional solvent extraction, which struggles to break cell structures and may cause flavonoid degradation at high temperatures (170°C). Additionally, the measurement standard used in the previous study, catechin equivalents (CE), may not have proved effective in obtaining the whole range of flavonoids as quercetin equivalents (QE), which is another factor for the difference. The higher TFC here demonstrates the UAE's potential for extracting bioactive compounds sustainably.

In one previous study, a much higher TFC for sea buckthorn seed dregs was reported (277.356 ± 16.141 mg CE/g) (Wei et al., 2023), showing its rich flavonoid glycosides content and exhibiting strong antioxidant activity. This high flavonoid content underlines sea buckthorn seed dregs' potential as a natural antioxidant source, as flavonoids are known to scavenge free radicals and suppress oxidative processes (Jomova et al., 2025). In comparison, the TFC content of coconut dregs extract is typically thought to be lower than that of sea buckthorn seed dregs. The lower amount of TFC in coconut dregs extract may explain its more modest antioxidant efficacy as compared to sea buckthorn seed dregs, as flavonoids play a critical part in antioxidant processes. After all, sea buckthorns are well known as one of the natural antioxidant sources rich in polyphenols such as flavonoids, phenolic acids, and anthocyanins, and have been used in various industries (Sytařová et al., 2020).

The DPPH assay is a widely used method for evaluating antioxidant activity by measuring the inhibition of lipid oxidation and the scavenging of DPPH radicals, which reflects the sample's free radical scavenging capacity (Gulcin & Alwasel, 2023). The DPPH inhibitory effect of coconut dregs extract was 77.15 ± 1.58%, indicating strong free radical scavenging activity. This was significantly higher than the result reported by Du et al. (2019) for coconut dregs flour extract, highlighting the superiority of UAE with DES over subcritical water extraction (SWE). The lower activity in SWE was likely due to high temperatures (180°C), degrading heat-sensitive antioxidants, and water's limited ability to extract less polar compounds. According to a previous study, temperatures between 60°C and 80°C are considered effective for maximizing flavonoid yield while minimizing degradation, and the higher extraction of phenolics and flavonoids for *Curcuma Zedoaria* leaves in their study was found to be 75 °C (Azahar et al., 2017). On the other hand, the UAE combined with DES offers a more adaptable solvent that can extract more types of bioactive substances while maintaining their efficacy. The increased TPC and TFC observed in this study are consistent with this trend of higher antioxidant activity, which confirms the usefulness of UAE with DES for improving the functioning and recovery of bioactive components from coconut dregs.

Previous studies by Rosni et al. (2024) on sesame seeds reported that the percentage of DPPH free radical scavenging on unfermented black sesame seed dregs had the highest antioxidant activity compared to fermented seeds. Unfermented black sesame seed dregs inhibited 93.71 ± 0.89% of radicals at 12.5 mg/mL, outperforming coconut dregs in this regard. Even fermented black sesame seed dregs performed better, with higher inhibitory percentages than coconut dregs extracted at the same doses. This result emphasises the higher antioxidant potential of black sesame seed dregs compared to coconut dregs. Similarly, it was reported that olive fruit dregs extracted via subcritical water (SCW) achieved 95.36 ± 2.03% inhibition, outperforming methanol extracts (50.42 ± 3.78%) (Yu et al., 2015). In comparison, coconut dregs extract exhibited antioxidant activity, as proven by its ability to reduce lipid oxidation in coconut oil. However, investigations using DPPH assays on coconut dregs extract have generally demonstrated a more moderate radical scavenging efficacy than olive fruit dregs).

3.2 Thiobarbituric acid reactive substance (TBARS)

Malondialdehyde (MDA) formation contributes to off-flavours in oils (Patil et al., 2023). Lipid peroxidation was assessed using the Thiobarbituric Acid Reactive Substances (TBARS) assay, which quantifies MDA levels in lipid-containing foods like oil and meat. This method involves reacting the sample with thiobarbituric acid to form a red complex, measured at 532 nm, with color intensity indicating oxidation levels (Mariutti, 2022). TBARS values are influenced by environmental factors like light, temperature, and oxygen, with lower temperatures and reduced oxygen slowing oxidation.

On Day 0, TBARS values were low with no significant differences, indicating minimal lipid peroxidation (Fig. 1). Over time, the control (CON) showed the highest TBARS values, peaking at 1.5419±0.0361 MDA eq/kg on Day 15, highlighting rapid oxidation without antioxidants.

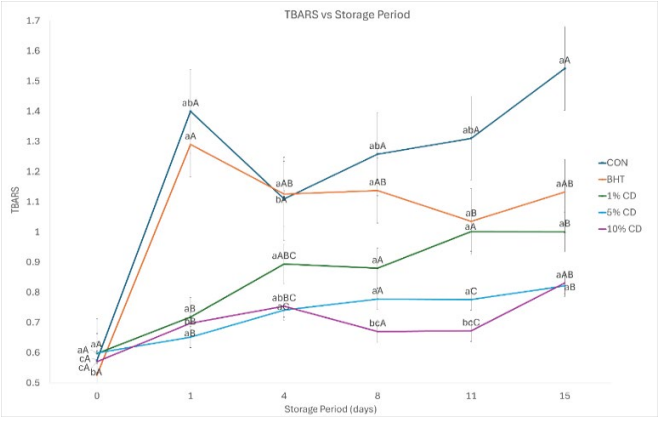

Fig. 1. TBARS values (MDA eq/kg) of coconut oil storage. The values represent the mean ± standard deviation from triplicate analyses (n = 3). Significant differences were observed at $p < 0.05$. Abbreviations: CD = Coconut Dregs. Small letters (a, b, c, d) indicate significant effects of storage time, while capital letters (A, B, C, D) indicate significant effects of extract addition on each storage day.

BHT-treated samples exhibited greater stability, with TBARS rising slowly to 1.1326±0.0406 MDA eq/kg. CD extract, particularly at 5% and 10%, effectively inhibited oxidation, yielding lower TBARS values (0.8214±0.0731 and 0.8312±0.0368 MDA eq/kg). The 1% CD treatment showed moderate protection (1.0010±0.3850 MDA eq/kg). Surprisingly, the differences between 5% CD and 10% CD were not statistically significant, suggesting that 5% CD is adequate to provide effective antioxidant protection.

One study reported the effect of cashew apple dreg extract (0.5% - 2.5%) and BHA (0.01%) on TBARS values in coconut oil over 20 days (Anwar, 2017), and found that the highest concentration (2.5%) of cashew apple dreg extracts lowered TBARS readings to 0.312 ± 0.029 MDA eq/kg by day 20, similar to the synthetic antioxidant BHA (0.309 ± 0.036 MDA eq/kg). This result suggests that coconut oil has considerable antioxidant activity in preventing lipid oxidation over extended storage periods (Subajiny et al., 2018). Likewise, coconut dregs extract, particularly at 5% and 10%, effectively maintained oxidative stability, comparable to synthetic antioxidants. However, cashew apple dreg extract achieved similar protection at lower concentrations (2.5%), while coconut dreg extract required up to 10% for equivalent results, showing that cashew apple dreg extract possesses a more potent antioxidant capacity. This observation suggests that the bioactive compounds present in cashew apple dregs, such as vitamin C, polyphenols, and flavonoids, may be more concentrated or more effective in preventing oxidative degradation compared to those in coconut dregs.

3.3 ρ-Anisidine value (AV)

The anisidine value (AV) measures secondary oxidation products in coconut oil, indicating oxidative stability. It reflects the breakdown of organic peroxides into aldehydes, ketones, and acids. AV is determined by reacting to aldehydes with p-anisidine to form a colored Schiff base, measured at 350 nm (Kedir et al., 2023). This simple and effective method showed AV values ranging from 1.11 to 4.18 over 15 days. Oils without antioxidants had the highest AV, signifying advanced oxidation, while BHT and coconut dregs extract (CD) significantly lowered AV, enhancing oxidative stability ($p \leq 0.05$).

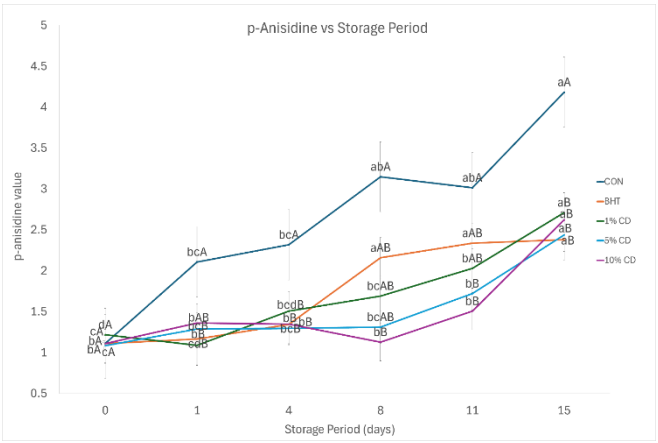

Fig. 2. p-anisidine values of coconut oil storage. The values represent the mean ± standard deviation from triplicate analyses (n = 3). Significant differences were observed at $p < 0.05$. Abbreviations: CD = Coconut Dregs. Small letters (a, b, c, d) indicate significant effects of storage time, while capital letters (A, B, C, D) indicate significant effects of extract addition on each storage day.

Initially, no significant differences were observed among treatments, as shown in Fig. 2, indicating uniform antioxidant content. Over time, oxidative changes have varied. The oil sample control exhibited the highest p-anisidine values throughout storage, peaking at 4.184±0.190 on day 15. This significant increase indicates intense oxidative degradation in the absence of antioxidants, as p-anisidine values measure aldehydes formed during lipid oxidation (Talbot, 2016). BHT-treated samples showed moderate protection (2.382±0.105), confirming its antioxidant role. CD extract at 5% and 10% outperformed BHT, with values of 2.440±0.252 and 2.623±0.292, respectively, likely due to phenolic compounds. The 1% CD extract treatment was less effective, showing higher p-anisidine values compared to higher concentrations. This suggests that a minimum CD extract concentration is essential for significant antioxidant activity. Statistical analysis revealed no significant differences between the 5% CD and 10% CD treatments at the end of the storage period, implying that 5% CD extract could be a cost-effective alternative while maintaining antioxidant efficiency.

These results support the findings of Chandran et al. (2017), who studied how ginger (CNO_{G-1}), pepper (CNO_{P-1}), and a synthetic antioxidant (CNO_T) affected oxidative stability

in coconut oil. Over seven weeks, CNO_{G-1} showed the best protection, with AV rising from 2.87 ± 0.76 to 13.84 ± 0.88, while CNO_{P-1} and CNO_T increased from around 2.5 to over 14. According to Hasanela et al. (2023), ginger contains various phytochemicals, including flavonoids and phenolic compounds, which contribute to its antioxidant activity. In comparison, coconut dregs (CD) extract in this study also helped slow down the rise in AV, particularly at higher concentrations, demonstrating its antioxidant potential. Although this study had a shorter storage period, the reduced AV in CD-treated samples highlights its effectiveness in minimizing secondary lipid oxidation, like ginger and pepper extracts.

3.4 Peroxide value (PV)

The peroxide value (PV) measures oil oxidation, indicating freshness and quality. Higher PVs signal increased fat degradation and rancidity (Rahman et al., 2017; Drinić et al., 2020). PV is commonly used to assess the oxidation level of fats and oils and reflects the degree of rancidity or oxidation, though it does not indicate stability (Kedir et al., 2023). In this study, PVs rose steadily over 15 days, ranging from 0.75 to 6.75 meqO_2/kg. Oils without antioxidants showed the highest PVs, nearly doubling those treated with BHT or coconut dregs extract (CD). While CD extract slowed oxidation ($P \leq 0.005$), no significant differences were observed between antioxidant-treated groups. A notable difference emerged only between the control, BHT, and CD extract on day 4.

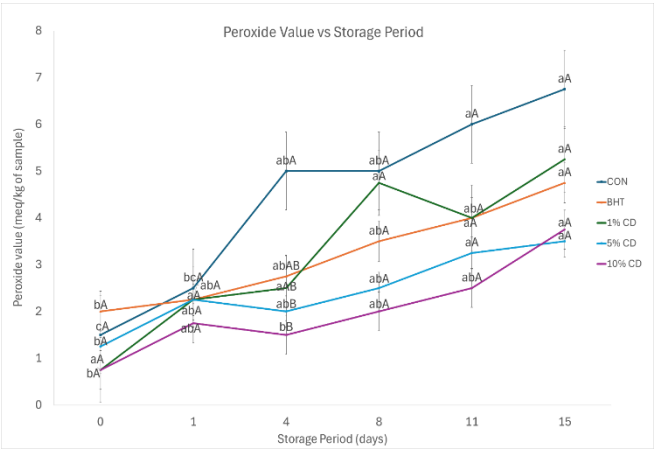

Fig. 3. p-anisidine values of coconut oil storage. The values represent the mean ± standard deviation from triplicate analyses (n = 3). Significant differences were observed at $p < 0.05$. Abbreviations: CD = Coconut Dregs. Small letters (a, b, c, d) indicate significant effects of storage time, while capital letters (A, B, C, D) indicate significant effects of extract addition on each storage day.

At the start of storage, all samples had low PVs, showing minimal initial oxidation. As time passed, the control sample experienced the most oxidation, reaching a PV of 6.750±0.354 on day 15, as shown in Fig. 3. This highlights the extent of oxidative degradation without antioxidant protection. In contrast, BHT-treated samples showed better stability with a final PV of 4.750±1.770. Coconut dregs (CD) extract also slowed oxidation, especially at 5% and 10% concentrations, which had the lowest PVs (3.500±0.707 and 3.750±0.354). This result suggests the phenolic compounds in CD extract effectively neutralise free radicals. Interestingly, there was no significant difference between 5% and 10%, meaning 5% CD extract may already provide strong antioxidant protection. On the other hand, the 1% CD extract treatment showed less effectiveness, with a PV of 5.250±1.770 by day 15, suggesting a higher concentration of CD extract is necessary to achieve meaningful oxidative stability.

This result shares a similar result made by Lestari et al. (2023), highlighting the strong antioxidant properties of clove. Clove effectively maintained low peroxide values (PV) throughout storage, likely due to its high eugenol content. Cloves are also known to contain various bioactive compounds such as eugenol, acetyl eugenol, and caryophyllene, which contribute to their notable health-promoting effects, including anti-inflammatory, pain-relieving, and antibacterial activities (Abdul Aziz et al., 2023). In comparison, coconut dregs (CD) extract also helped slow oxidation, but its effectiveness was more gradual. While CD extract contains beneficial compounds like phenolics and flavonoids, its antioxidant activity may not be as stable or potent as clove. This comparison highlights the potential differences in antioxidant efficacy caused by each extract's specific bioactive component composition. The addition of carrot powder significantly improved the stability of coconut oil by lowering peroxide numbers and inhibiting oxidation, thus maintaining oil quality better than CD and BHT (Suaniti et al., 2019).

3.5 Total Oxidation (TOTOX) Index

The oxidative stability of coconut oil over 15 days of storage was evaluated based on the Total Oxidation (TOTOX) values (Table 2), reflecting the combined presence of primary and secondary oxidation products. A TOTOX index lower than 30 indicates a vegetable oil with a maximum of 10 meqO2 (kg-1 of oil) as PV and a maximum of 10 as p-AnV. Largely, a TOTOX index lower than 30 is expected for a vegetable edible oil (Giuffrè et al., 2017). From the results, a gradual increase in TOTOX values was observed over time across all treatments, indicating the progressive oxidation of lipids during storage.

As expected, the control sample (without antioxidant) exhibited the highest TOTOX values throughout the storage period, reaching 17.68 ± 0.90 by day 15. This result clearly reflects the susceptibility of untreated coconut oil to oxidation, particularly under elevated temperature conditions. In

contrast, the addition of antioxidants, both synthetic butylated hydroxytoluene (BHT) and natural (coconut dregs extract), demonstrated a protective effect against lipid oxidation. In this study, the BHT-treated sample showed lower TOTOX values compared to the control, particularly at later storage stages (d8 to d15), with the final value recorded at 11.88 ± 3.43. It confirms the established antioxidant efficacy of BHT in retarding oxidative reactions in edible oils. However, interestingly, certain concentrations of coconut dregs (CD) extract offered comparable or even superior performance.

Moreover, at 1% CD, the antioxidant effect observed was moderate, with TOTOX values rising to 13.21 ± 3.59 at day 15, indicating that a low concentration of the extract was insufficient to maintain prolonged stability. However, increasing the concentration to 5% and 10% CD resulted in a more pronounced antioxidant effect. The 5% CD treatment consistently maintained lower TOTOX values than BHT across the storage period, recording 9.44 ± 1.16 on day 15. Meanwhile, 10% CD displayed the most promising results, with the lowest initial value of 2.61 ± 0.57 and a final value of 10.12 ± 0.99, showing sustained protection against oxidative degradation.

Table 2. TOTOX values of coconut oil storage

Storage time (ST)	Antioxidant (A)				
	CON	BHT	1% CD	5% CD	10% CD
d0	4.112±1.4 05^{cA}	5.110±1.4 40^{aA}	2.721±0.7 92^{bA}	3.586±0.6 93^{cA}	2.612±0.5 69^{bA}
d1	7.110±1.6 80^{bcA}	5.667±0.5 52^{aA}	5.591±0.9 14^{abA}	5.790±0.8 56^{abcA}	4.863±0.8 34^{bA}
d4	11.980±1. 560^{abcA}	6.850±2.0 90^{aAB}	6.508±0.1 39^{abB}	5.297±0.1 16^{bcB}	4.350±1.4 12^{bB}
d8	13.150±2. 430^{abA}	9.160±2.5 80^{aA}	11.190±2. 120^{abA}	6.312±1.3 42^{abcA}	5.129±1.3 88^{abA}
d11	15.020±3. 130^{abA}	10.340±4. 160^{aA}	10.030±3. 010^{abA}	8.223±0.9 22^{abA}	6.510±1.9 20^{abA}
d15	17.684±0. 897^{aA}	11.880±3. 430^{aA}	13.210±3. 590^{aA}	9.440±1.1 62^{aA}	10.123±0. 999^{aA}

The values represent the mean ± standard deviation from triplicate analyses (n = 3). Significant differences were observed at $p < 0.05$. Abbreviations: CD = Coconut Dregs. Different letters within a column (a, b, c, d) indicate significant effects of storage time. In contrast, different letters within a row (A, B, C, D) indicate significant effects of extract addition on each storage day.

Both 5% and 10% CD significantly improved oxidative stability; however, the differences between these two concentrations were not consistently significant across storage intervals. Thus, 5% CD is proposed to be sufficient to exert maximum antioxidant capacity, and increasing the dosage beyond this point may not yield proportionate benefits in terms of oil protection. The enhanced performance of CD extract at higher concentrations could be attributed to the presence of phenolic and flavonoid compounds with free radical scavenging properties, as previously quantified. Furthermore, the efficacy of CD extract here was found to be comparable to BHT, thus supporting its application in the development of edible oil-based products

4. CONCLUSION

In conclusion, this study confirms deep eutectic solvents (DES) as an efficient, eco-friendly method for extracting bioactive compounds from coconut dregs, yielding phenolics (44.259±0.059 mg GAE/g) and flavonoids (24.211±0.469 mg QE/g). DES proved a viable green alternative to traditional extraction, producing an antioxidant-rich extract beneficial for food preservation. Coconut oil stability was assessed over 15 days, with CD extract significantly reducing oxidative degradation. Higher extract concentrations enhanced stability, comparable to synthetic BHT, which can effectively extend shelf life. Future research could explore coconut dregs extract as an antioxidant in various edible oils and optimise its extraction using sustainable methods. A comparative study on oils like sunflower, palm, olive, and soybean could assess oxidative stability using peroxide value, p-anisidine value, and TOTOX, with advanced techniques like Gas Chromatography-Mass Spectrometry (GC-MS) and Fourier Transform Infrared (FTIR) identifying oxidation byproducts. Additionally, optimising DES-based extraction by comparing ultrasound-assisted (UAE), supercritical fluid (SFE), and microwave-assisted (MAE) methods could enhance efficiency, antioxidant yield, and sustainability, supporting natural antioxidant production and agricultural waste utilisation.

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