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Activated carbons made from cocoa (*Theobroma cacao*) and coconut (*Cocos nucifera*) shells can be used as adsorbents to improve the quality of frying oils

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Abstract

This research study aimed to evaluate the ability of activated carbons derived from cocoa and coconut shells to eliminate oxidation products and regenerate frying oils. The powders were activated, after which they were carbonised at various temperatures. The resulting activated carbons were characterised using the Boehm and methylene blue method. The best adsorbent activated carbons, as well as their mixtures, were used to treat/filter oxidised oils collected after 8, 16 and 24 frying cycles. The primary (hydroperoxides) and secondary (aldehydes) oxidation products and the free fatty acids were quantified before and after treatment using standardised methods. A sensory evaluation of doughnuts fried in the filtered oils was also conducted. The results of the study demonstrate that carbonised cocoa shells (CoAS) at 300°C and carbonised coconut shells at 200°C exhibit superior porosity, a substantial adsorption surface area and a high proportion of acidic functions (34.4%–35%). Activated carbons made from CoAS and from the mixture cocoa–coconut shells at 15% demonstrated their ability to reduce impurities (hydroperoxides, aldehydes) in frying oil and to improve organoleptic properties of deep-fried products. This study can be used as a benchmark for the valorisation of these agricultural by-products in the production of natural adsorbents for oil regeneration.

KEYWORDS

activated carbons, adsorbent, cocoa shells, coconut shells, frying oils

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1 | INTRODUCTION

Frying is a complex dehydration process that is widely used on a commercial and domestic scale. Numerous chemical and physical changes occur in the frying medium and the fried products during this process. These changes are mainly due to the processes of hydrolysis, oxidation and polymerisation, all of which promote the degradation of frying oils.[1,2] These reactions result in primary and secondary oxidation products, such as peroxides, aldehydes (malondialdehyde, 4-hydroxynonenal, hexanal), glycidol, epoxides, acrylamide and 3-monochloropropane-1,2-diol that are recognised as harmful to consumer health.[3,4] These changes also affect the nutritional quality and the sensory attributes of frying products. The International Agency for Research on Cancer [5] has classified most of these compounds as possibly carcinogenic to humans. Cooking oil is absorbed by food during the cooking process. Good hygiene standards are therefore crucial for frying oil, as consumer acceptance of fried products depends on them.

There are several methods of preventing or eliminating the appearance of these oxidation products in oils. One such method involves using activated carbon (adsorbent materials) that can bind to and reduce the presence of harmful organic compounds in oxidised oils.[6,7] In addition, the treatment of frying oils with adsorbents has been shown to be easy to apply.[8] In developed countries, synthetic adsorbents such as Magnesol®, OilFresh™ and Frypowder are commonly used to filter oil during frying, enabling the same oil to be used repeatedly.[9,10] However, although these materials are effective at filtering oils, they are difficult to access in developing countries due to their limited availability and high cost. This makes the prospect of facilitating oil regeneration during frying questionable and worrying in these countries.

Sustainable solutions have been explored for several years through research into easily accessible natural sources of raw materials for the production of adsorbents. Agricultural waste is the most promising source for the production of bio-adsorbents, which are more economical and environmentally friendly. These materials have a large surface area, which provides ample site for adsorption.[11] The use of this waste would be an innovation because it would add value to these by-products, which are usually discarded. Several research activities have already yielded interesting results. For example, Waqar et al.[7] recently demonstrated that sugarcane bagasse has a large surface area and is capable of adsorbing hydroperoxides and other oxidation products. Teboukeu et al.[12] showed that activated carbons made from peanut and rice husks can regenerate frying oils by adsorbing hydroperoxides and aldehyde compounds, both of which are harmful to health and present in oils. Despite the large number of natural adsorbents (activated carbons) that have been produced to date, very few have been validated and approved. This highlights the importance of seeking out more.

Cocoa and coconut shells have a high carbon content and are rich in compounds such as cellulose, lignin, and hemicellulose.[13] This composition gives them porous properties and numerous active adsorption sites, making them useful for purifying used oils. Khuzaimah and Eralita[14] and Rini and Ade[15] have demonstrated the ability of coconut and cocoa shells (CoAS) to bind and reduce the levels of free fatty acids and hydroperoxides in cooking oils. However, these previous studies did not focus on characterising these adsorbents. Furthermore, they did not evaluate these bioadsorbents' ability to purify oils by eliminating secondary oxidation products (mainly aldehydes), which are more stable and dangerous to human health.

This research work aims to characterise cocoa and coconut shell adsorbents, and evaluate their ability to remove oxidation products from frying oils.

2 | MATERIAL AND METHODS

2.1 | Material

The cocoa and coconut shells used were collected from agricultural producers at Loum, Moungo Division, Littoral-Cameroon, in November 2024. Fresh and used palm olein was collected from a local doughnut vendor at Dschang, Menoua Division, West-Cameroon, in January 2025. All the chemicals and reagents used were of analytical reagent grade.

2.2 | Methods

2.2.1 | Preparation of activated carbon from cocoa and coconut shells

Once collected, the shells were cleaned, washed, dried at 80°C and crushed into small fragments. The materials were ground and sieved using a 500 μm sieve. The resulting powders were impregnated in a 1.5% NaOH solution for 24 h and then dried in an oven at 105°C for a further 24 h. Once dried, the powder from each material were divided into three batches, which were then carbonised at temperatures of 200 ± 5, 300 ± 5 and 400 ± 5°C for 2 h. After calcination, the activated carbons obtained were cooled and rinsed several times with distilled water until the pH of the rinse water was between 6.5 and 7. They were then dried again in an oven at 105°C for 24 h.

2.2.2 | Characterisation of activated carbons

The characterisation of activated carbons enabled the selection of the material with the best adsorption capacity and largest functional surface area.

Methylene blue value: The method of the Conseil Européen des Fédérations de l'Industrie Chimique[16] and updated by Mamane et al.[17] was used to evaluate the ability of activated carbons to adsorb medium and large organic molecules. A mass of 0.1 g of activated carbon was added to 100 mL of 1.944×10^{-5} M methylene blue (MB) solution. The mixture was agitated for 20 min at room

temperature on an Edmund Bühler GmbH multi-station stirrer at 175 rpm and then filtered using Whatman No. 4 filter papers. The residual concentration of MB in the filtrate was determined by UV-visible spectrophotometry at a wavelength of 620 nm. The MB value (mg/g) was calculated using Equation (1):

$$\text{Methylene blue value} = \frac{V \times M \times (\text{Ci}-\text{Cr})}{\text{Mc}}, \quad (1)$$

where *V*, volume of MB solution (mL); *M*, molar mass of MB (g/mol); Ci, initial concentration of MB in (mol/L); Cr, residual concentration of MB in (mol/L) and Mc, mass of activated carbon (g).

Determination of surface functions by the Boehm method: The total basic and acidic functions on the surface of activated carbons were determined by the Boehm method.[18] The determination of the acidic surface functions such as carboxylics and lactonics was done by putting in a closed reactor, 0.1 g of the activated carbon and 30 mL of 0.1 M solutions of Na_2CO_3 and NaOH, respectively. The basic surface functions were determined by replacing the basic solutions with 0.1 M solution of HCl. The mixtures obtained were agitated at 175 rpm for 24 h at room temperature and then filtered. The excess bases (Na_2CO_3 and NaOH) contained in the filtrates, were determined by titration using the previously prepared HCl solution, whereas the excess acid (HCl) in the filtrates was determined by titration with the previously prepared NaOH solution. From these excess amounts of acid and base left in the filtrates, it was possible to deduce the corresponding amounts of acids and bases neutralised, respectively, by basic and acidic surface functions of the adsorbents.

2.2.3 | Treatment of different oil samples using adsorbents (filtration)

The palm olein samples collected from local doughnut sellers consisted of fresh (unused) oil and oil that had been used after 8, 16, and 24 frying cycles.

Cocoa and coconut shell adsorbents, which have the best properties, were used at concentrations of 5% and 15% during oil regeneration. A combination of equal parts of these two adsorbents was also used. The synthetic adsorbent MirOil P100 Fry Powder Oil, which has already been shown to be effective in regenerating oils, was also used.

The adsorbents were mixed with fresh and used oil in a weight/volume ratio of 5% and 15% at 105°C, stirred for 45 min and separated by centrifugation at 3000 rpm for 45 min. The treated oil samples were stored in dark glass bottles until analysis.

2.2.4 | Chemical characterisation of treated (using adsorbents) and untreated oil

Several indicators were used to measure the degree of rancidity and quantify the primary and secondary oxidation products in the oils, both before and after they were filtered using adsorbents. Peroxide value (PV) was evaluated following the spectrophotometrical International Dairy Federation standard method, 74A: 1991.[19] *p*-Anisidine value (AV) was determined according to American Oil Chemists' Society (AOCS) Official Method CD 18–90.[20] Thiobarbituric acid (TBA) value was carried out according to the method described by Draper and Hadley[21] and the acid value of oil samples was evaluated using the AOCS official method Ca 5a-40.[22] The total oxidation value (TOTOX) was calculated using the following equation: TOTOX = 2 PV + AV.[23] All measurements were carried out in duplicates.

2.2.5 | Evaluation of adsorbent efficiency

The activated adsorbents and their combination were assessed for their ability to enhance oil quality using the percentage improvement (%PI) formula represented by Equation (2):

$$\text{Percentage improvement} = \frac{(\text{Value of untreated oil} - \text{Value of treated oil}) \times 100}{(\text{Value of untreated oil})}. \quad (2)$$

2.2.6 | Sensory evaluation of local doughnuts fried in treated oils

A sensory analysis of locally produced doughnuts fried in oils treated with various adsorbents was conducted to evaluate the impact of the treatment on the products' organoleptic properties and acceptability. Strict ethical guidelines were adhered to in order to protect the rights and privacy of the participants. Ethical clearance was obtained from the Regional Committee for Ethics in Human Health Research of the West Region (CRERSH-West) with Project Identification Number: 544/30/04/2025/CE/CRERSH-OU/VP.

Tests were performed on four samples (fresh oil, fried in untreated oil after a 16-cycle frying process and in oil treated with cocoa and coconut shell adsorbents) based on a consumer acceptance test using a 9-point hedonic scale. The odour, colour, taste, texture and overall acceptability of the products were assessed by 30 semi-trained panel members, from whom informed consent was initially obtained.[24] Prior to the sensory tests, the panellists (lecturers and students from around the university campus) were given an orientation. The doughnuts were coded and presented to the panellists individually to prevent interaction between them that could influence their responses. Each panellist was seated comfortably in an individual booth equipped with lighting and free from distractions. The panellists were recruited based on their familiarity with doughnuts. The degree to which a product was liked was scored as 9, 8, 7, 6, 5, 4, 3, 2 and 1 points, to express like extremely, like very much, like moderately, like slightly, neither like nor dislike, dislike slightly, dislike moderately, dislike very much and dislike extremely, respectively. The panellists were advised to take just one sample of each coded doughnut. Each panellist was given a cup of clean

water to rinse their mouth between testing each sample, to avoid a carry-over effect.

2.3 | Statistical analysis

Raw data was computed using Microsoft Excel 2013. All data were presented as mean ± SD. Comparison of means was carried out using one-way analysis of variance with Dunnet and Student–Newman–Keuls test using GraphpadInStat version 3.05. A probability value at $p < 0.05$ was used for statistical significance.

3 | RESULTS AND DISCUSSION

3.1 | Characterisation of the activated carbons

3.1.1 | Methylene blue adsorption onto activated carbons

Figure 1 shows the MB absorption capacity of various cocoa and coconut shell samples carbonised at different temperatures. With the exception of the coconut sample carbonised at 400°C, all other samples showed relatively similar values. The highest absorption capacities were observed in CoAS at 300°C (79.62 mg/g) and in coconut shells at 200°C (80.76 mg/g). MB absorption capacity is a measure of the specific surface area of activated carbon, an important parameter for assessing the adsorption process. Higher MB absorption indicates a greater specific surface area of the activated carbon.[25] Therefore, a high MB value indicates strong adsorption capacity and a large specific surface area, suggesting that activated carbon could be effective in removing impurities from cooking oils. The activated carbons obtained at 300°C for CoAS and 200°C for coconut shells showed the higest MB adsorption capacity and so were used for surface functional group quantification and also in subsequent parts of this work.

3.1.2 | Surface functional groups quantification on the selected activated carbons

The results obtained from Boehm titration are summarized in Table 1. It appears that the two selected activated carbons have a higher proportion of acidic functions (34.4%–35%) than basic functions (15.2%–15.4%), with the carboxylic function (–COOH) being the most prevalent. The presence of these two functions in the activated carbons suggests that they are capable of adsorbing both anionic and cationic adsorbates.[26] Buczek and Chwiakowski[27] demonstrated that carboxylic groups are polar and can form hydrogen bonds with polar oxidation products, such as hydroperoxides, alcohols, and aldehydes, which are formed during the oxidation of oils. Basic groups can form ionic bonds with free fatty acids produced during oil oxidation. These results are consistent with those of Kouadio et al.[28] who also found that activated carbon derived from CoAS exhibits a higher proportion of acidic functions than basic functions.

3.2 | Effect of activated carbon derived from cocoa and coconut shells on the quality of frying oils

3.2.1 | Measurement of primary oxidation products using the peroxide value

Table 2 shows the variation in the PV and the percentage improvement in different oil samples after treatment with activated carbon at various concentrations. As can be seen, the PV increases with the number of frying cycles, rising from 8.38 ± 0.93 to 15.91 ± 0.00 ppm after 24 cycles. This increase reflects the oxidation of fatty acids to produce hydroperoxides, which are the primary markers of oxidation in frying oils.

The treatment of oils generally showed a decrease in the PV regardless of the oil sample and the concentration of adsorbent used. Activated carbons and synthetic adsorbents at 15% showed greater activity with better percentages of improvement in oil quality. Oil samples treated with CoAS and the mixture (CoAS + CoNS) showed a significant decrease ($p < 0.05$) in the PV with quality improvement percentages of 8.85%–37.57% and 13.12%–43.49%, respectively, after 24 frying cycles. The filtering capacity of these adsorbents is relatively comparable to that of synthetic adsorbents. The results also showed that oils that had undergone 24 frying cycles were the most significantly improved in quality after treatment. The decrease in the PV and the improvement in quality can be explained by the fact that the -OH groups of the carboxylic functions on the adsorbent surface bind the hydroperoxides present in the oxidised oils and reduce their concentration.[27,29] These results are consistent with those reported by Rini and Ade[15] who also demonstrated the effectiveness of activated carbon derived from CoAS for oil regeneration.

3.2.2 | Measurement of secondary oxidation products using the anisidine and TBA value

The secondary oxidation products measured by these parameters are malonaldehyde (TBA value), 2-alkenal and 2,4-alkadienal (anisidine value).[30,31] Table 3 shows the variation in the TBA value and the percentage improvement in oil quality at different frying cycles. The data show that the TBA value increases with the number of frying cycles, with values ranging from 0.77 ± 0.40 to 5.01 ± 0.68 mg MDA/kg. Overall, filtering the oils using different adsorbents led to a decrease in the TBA value, regardless of concentration. Oils treated with 15% of CoAS or 15% of their mixture (CoAS + CoNS) showed the most significant decreases.

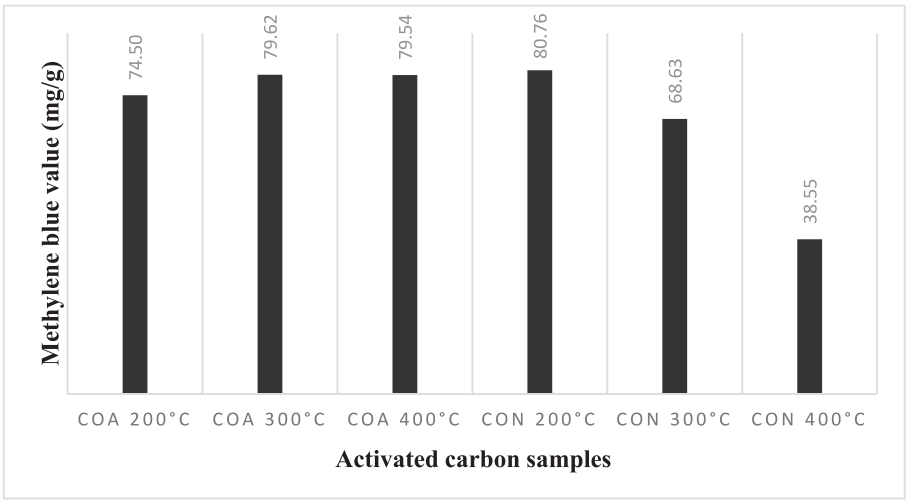


FIGURE 1 Methylene blue value of cocoa (CoA) and coconut (CoN) shells at different carbonisation temperatures.

TABLE 1 Functional groups of selected activated carbons.

	Acids			
Samples	**Carboxyl**	**Lactone**	**Total acids**	**Basics**
Cocoa (CoA) shells	2.88 (20.4%)	2.06 (14.6%)	4.94 (35.0%)	2.18 (15.4%)
Coconut (CoN) shells	2.88 (20.4%)	1.98 (14.0%)	4.86 (34.4%)	2.15 (15.2%)
Totals (%)	5.76 (40.8)	4.04 (28.6%)	9.8 (69.4%)	4.33 (30.6%)

TABLE 2 Peroxide value and the percentage improvement in the quality of frying oils collected at different frying cycle and treated with activated carbons.

Proxide value (PV) (ppm)						
Samples	**PV**	**PV improvement (%)**	**PV**	**PV improvement (%)**	**PV**	**PV improvement (%)**
Fresh oil	8.38 ± 0.93^{a}	ND	8.38 ± 0.93^{a}	ND	8.38 ± 0.93^{a}	ND
Oil collected after 8 frying cycles	11.08 ± 0.00^{b}	ND	11.08 ± 0.00^{b}	ND	11.08 ± 0.00^{b}	ND
Oil collected after 16 frying cycles	13.46 ± 1.60^{c}	ND	13.46 ± 1.60^{c}	ND	13.46 ± 1.60^{c}	ND
Oil collected after 24 frying cycles	15.91 ± 0.00^{d}	ND	15.91 ± 0.00^{d}	ND	15.91 ± 0.00^{d}	ND
	Collected after 8 frying cycle		**Collected after 16 frying cycle**		**Collected after 24 frying cycle**	
Oil treated with 5% SA	10.65 ± 0.31^{b}	3.79	10.93 ± 2.83^{ab}	18.72	11.48 ± 1.39^{bc}	27.81
Oil treated with 15% SA	9.59 ± 0.00^{ab}	13.41	11.75 ± 0.30^{b}	12.68	9.55 ± 1.13^{ab}	40.00
Oil treated with 5% CoAS	10.34 ± 0.87^{b}	6.57	12.24 ± 1.05^{bc}	8.97	11.77 ± 0.00^{b}	26.05
Oil treated with 15% CoAS	10.09 ± 0.00^{b}	8.85	10.31 ± 0.52^{b}	23.34	9.93 ± 0.47^{be}	37.57
Oil treated with 5% CoNS	11.17 ± 0.62^{b}	NI	12.41 ± 0.00^{c}	7.72	10.42 ± 0.00^{be}	34.51
Oil treated with 15% CoNS	9.62 ± 0.75^{ab}	13.08	10.76 ± 0.00^{b}	20.03	10.83 ± 0.00^{b}	31.93
Oil treated with 5% CoNS + CoAS	11.03 ± 0.00^{b}	0.33	10.72 ± 0.00^{ab}	20.29	11.82 ± 0.00^{f}	25.70
Oil treated with 15% CoNS + CoAS	9.62 ± 0.00^{ab}	13.12	10.48 ± 0.99^{b}	22.07	8.99 ± 0.00^{a}	43.49

Note: Values are expressed as mean ± SE ($n = 2$). Means in the same column not sharing the same superscripts are significantly different at ($p < 0.05$).
Abbreviations: CoAS, cocoa shells adsorbent; CoNS, coconut shells adsorbent; CoNS + CoAS, mixture of cocoa and coconut shells adsorbent; NI, no improvement; ND, not determined; SA, synthetic adsorbent.

TABLE 3 TBA value and the percentage improvement in the quality of frying oils collected at different frying cycle and treated with activated carbons.

TBA value (mg MDA/kg)						
Samples	**TBA value**	**TBA value improvement (%)**	**TBA value**	**TBA value improvement (%)**	**TBA value**	**TBA value improvement (%)**
Fresh oil	0.77 ± 0.40^{a}	ND	0.77 ± 0.40^{a}	ND	0.77 ± 0.40^{a}	ND
Oil collected after 8 frying cycles	1.98 ± 0.10^{b}	ND	1.98 ± 0.10^{d}	ND	1.98 ± 0.10^{ab}	ND
Oil collected after 16 frying cycles	1.95 ± 1.11^{b}	ND	1.95 ± 1.11^{cd}	ND	1.95 ± 1.11^{ab}	ND
Oil collected after 24 frying cycles	5.01 ± 0.68^{d}	ND	5.01 ± 0.68^{e}	ND	5.01 ± 0.68^{f}	ND
	Collected after 8 frying cycle		**Collected after 16 frying cycle**		**Collected after 24 frying cycle**	
Oil treated with 5% SA	1.66 ± 0.36^{bc}	16.23	1.92 ± 0.23^{d}	1.62	1.80 ± 0.19^{b}	64.16
Oil treated with 15% SA	0.65 ± 0.31^{a}	67.32	1.64 ± 0.07^{c}	16.01	1.70 ± 0.32^{b}	66.13
Oil treated with 5% CoAS	1.73 ± 0.38^{b}	12.75	1.50 ± 0.42^{bc}	23.13	2.46 ± 0.66^{c}	50.85
Oil treated with 15% CoAS	0.89 ± 0.25^{a}	54.95	1.27 ± 0.05^{b}	34.63	2.02 ± 0.08^{c}	59.73
Oil treated with 5% CoNS	1.91 ± 0.06^{b}	3.53	2.81 ± 1.04^{c}	NI	4.38 ± 0.69^{e}	12.55
Oil treated with 15% CoNS	2.19 ± 0.76^{c}	NI	2.65 ± 0.55^{d}	NI	3.13 ± 0.65^{d}	37.44
Oil treated with 5% CoNS + CoAS	1.80 ± 0.33^{b}	9.06	1.13 ± 0.30^{a}	41.96	2.32 ± 0.58^{cd}	53.69
Oil treated with 15% CoNS + CoAS	1.96 ± 0.26^{b}	0.89	1.41 ± 0.49^{bc}	27.59	2.54 ± 0.71^{cd}	49.38

Note: Values are expressed as mean ± SE ($n = 2$). Means in the same column not sharing the same superscripts are significantly different at ($p < 0.05$).
Abbreviations: CoAS, cocoa shells adsorbent; CoNS, coconut shells adsorbent; CoNS + CoAS, mixture of cocoa and coconut shells adsorbent; NI, no improvement; ND, not determined; SA, synthetic adsorbent.

After 24 frying cycles, these activated carbons produced the greatest quality improvement percentages (49.38%–59.73%) in the oxidised oil.

Table 4 illustrates the changes in the anisidine index and the percentage improvement in the quality of oils treated with activated carbon at various concentrations. This parameter also increases with the number of frying cycles. Of the oil samples, only the one that had not undergone any culinary treatment (fresh oil) showed an anisidine value (20.24 ± 0.62) that complied with the Codex Alimentarius[32] standard of 20. Analysis of the data reveals results similar to those observed in the measurement of the TBA value.

A decrease in the TBA and anisidine values indicates a reduction in the concentration of secondary oxidation products in the treated oil samples. Malonaldehydes, 2-alkenals and 2,4-alkadienals are highly polar compounds[33] which are adsorbed onto the surface of activated carbons via polar groups. Adsorption increases with adsorbent concentration as the surface area and number of polar groups involved in the mechanism increase. Furthermore, activating these carbons using NaOH improves their porosity and adsorption capacity.[25]

3.2.3 | Measurement of free fatty acid using the acid value

Table 5 shows the acid value and the percentage improvement in the quality of oil samples treated with activated carbons. This parameter also increases with the number of frying cycles. However, none of the adsorbents used during filtration improved the quality of oxidised oils in terms of their free fatty acid content. This could be explained by the low polarity and high molecular weight of free fatty acids, which makes adsorption by adsorbents difficult. In fact, free fatty acids are composed of a polar head (–COOH) and a long nonpolar hydrophobic tail (–H–C–).[12]

3.2.4 | Measurement of total oxidation (Totox)

The TOTOX measures hydroperoxides and their degradation products (secondary oxidation products), providing a more accurate indication of impurities in oxidised oils.[34] Table 6 provides an overview of the oxidation of oils treated with adsorbents. The variations observed are similar to those in Tables 2–4. These results confirm that CoAS and their mixture (CoAS + CoNS) at a concentration of 15% are the most effective at regenerating frying oils. Oils treated with these activated carbons showed the greatest improvement in quality.

3.3 | Hedonic sensory analysis of fried foods

To measure the impact of using these adsorbents on the organoleptic qualities of the food, oxidised oils treated with CoAS (15%) and CoAS + CoNS (15%) were used to fry doughnuts. Table 7

TABLE 4 Anisidine value and the percentage improvement in the quality of frying oils collected at different frying cycle and treated with activated carbons.

Anisidine value (AnV)						
Samples	AnV	AnV improvement (%)	AnV	AnV improvement (%)	AnV	AnV improvement (%)
Fresh oil	20.24 ± 0.62^{a}	ND	20.24 ± 0.62^{a}	ND	20.24 ± 0.62^{a}	ND
Oil collected after 8 frying cycles	63.00 ± 0.71^{f}	ND	63.00 ± 0.71^{b}	ND	63.00 ± 0.71^{b}	ND
Oil collected after 16 frying cycles	94.59 ± 1.64^{g}	ND	94.59 ± 1.64^{f}	ND	94.59 ± 1.64^{e}	ND
Oil collected after 24 frying cycles	118.65 ± 0.00^{h}	ND	118.65 ± 0.00^{g}	ND	118.65 ± 0.00^{h}	ND
	Collected after 8 frying cycle		**Collected after 16 frying cycle**		**Collected after 24 frying cycle**	
Oil treated with 5% SA	57.31 ± 5.08^{f}	9.03	81.18 ± 13.47^{de}	14.18	99.74 ± 2.39^{f}	15.94
Oil treated with 15% SA	38.88 ± 0.24^{cd}	38.28	69.49 ± 1.83^{cd}	26.53	83.50 ± 0.00^{d}	29.62
Oil treated with 5% CoAS	33.38 ± 1.92^{c}	47.01	76.50 ± 7.54^{de}	19.13	87.11 ± 4.13^{e}	26.58
Oil treated with 15% CoAS	28.00 ± 0.81^{b}	55.56	66.84 ± 0.59^{c}	29.33	74.33 ± 3.37^{c}	37.35
Oil treated with 5% CoNS	43.61 ± 2.91^{d}	30.78	85.26 ± 4.55^{e}	9.86	107.00 ± 8.31^{g}	9.82
Oil treated with 15% CoNS	40.12 ± 10.20^{cd}	36.32	72.70 ± 0.32^{d}	23.14	89.85 ± 5.80^{e}	24.27
Oil treated with 5% CoNS + CoAS	53.14 ± 1.51^{e}	15.66	81.24 ± 0.00^{e}	14.11	106.55 ± 5.62^{g}	10.20
Oil treated with 15% CoNS + CoAS	45.27 ± 1.26^{d}	28.14	71.25 ± 0.00^{d}	24.67	81.23 ± 2.64^{d}	31.54

Note: Values are expressed as mean ± SE ($n = 2$). Means in the same column not sharing the same superscripts are significantly different at ($p < 0.05$).
Abbreviations: CoAS, cocoa shells adsorbent; CoNS, coconut shells adsorbent; CoNS + CoAS, mixture of cocoa and coconut shells adsorbent; NI, no improvement; ND, not determined; SA, synthetic adsorbent.

TABLE 5 Acid value and the percentage improvement in the quality of frying oils collected at different frying cycle and treated with activated carbons.

Acid value (AV) (mg KOH/g)						
Samples	AV	AV improvement (%)	AV	AV improvement (%)	AV	AV improvement (%)
Fresh oil	1.12 ± 0.00^{a}	ND	1.12 ± 0.00^{a}	ND	1.12 ± 0.00^{a}	ND
Oil collected after 8 frying cycles	1.12 ± 0.00^{a}	ND	1.12 ± 0.00^{a}	ND	1.12 ± 0.00^{a}	ND
Oil collected after 16 frying cycles	2.24 ± 0.00^{b}	ND	2.24 ± 0.00^{b}	ND	2.24 ± 0.00^{b}	ND
Oil collected after 24 frying cycles	2.24 ± 0.00^{b}	ND	2.24 ± 0.00^{b}	ND	2.24 ± 0.00^{b}	ND
	Collected after 8 frying cycle		**Collected after 16 frying cycle**		**Collected after 24 frying cycle**	
Oil treated with 5% SA	1.12 ± 0.00^{a}	NI	2.24 ± 0.00^{b}	NI	2.24 ± 0.00^{b}	NI
Oil treated with 15% SA	2.24 ± 0.00^{b}	NI	2.24 ± 0.00^{b}	NI	2.24 ± 0.00^{b}	NI
Oil treated with 5% CoAS	2.24 ± 0.00^{b}	NI	2.24 ± 0.00^{b}	NI	2.24 ± 0.00^{b}	NI
Oil treated with 15% CoAS	1.12 ± 0.00^{a}	NI	2.24 ± 0.00^{b}	NI	2.24 ± 0.00^{b}	NI
Oil treated with 5% CoNS	2.24 ± 0.00^{b}	NI	2.24 ± 0.00^{b}	NI	3.37 ± 0.00^{c}	NI
Oil treated with 15% CoNS	2.24 ± 0.00^{b}	NI	2.24 ± 0.00^{b}	NI	2.24 ± 0.00^{b}	NI
Oil treated with 5% CoNS + CoAS	2.24 ± 0.00^{b}	NI	2.24 ± 0.00^{b}	NI	2.24 ± 0.00^{b}	NI
Oil treated with 15% CoNS + CoAS	3.37 ± 0.00^{c}	NI	2.24 ± 0.00^{b}	NI	3.37 ± 0.00^{c}	NI

Note: Values are expressed as mean ± SE ($n = 2$). Means in the same column not sharing the same superscripts are significantly different at ($p < 0.05$).
Abbreviations: CoAS, cocoa shells adsorbent; CoNS, coconut shells adsorbent; CoNS + CoAS, mixture of cocoa and coconut shells adsorbent; NI, no improvement; ND, not determined; SA, synthetic adsorbent.

TABLE 6 TOTOX value and the percentage improvement in the quality of frying oils collected at different frying cycle and treated with activated carbons.

TOTOX value (TOV)						
Samples	TOV	TOV improvement (%)	TOV	TOV improvement (%)	TOV	TOV improvement (%)
Fresh oil	37.00 ± 1.23^{a}	ND	37.00 ± 1.23^{a}	ND	37.00 ± 1.23^{a}	ND
Oil collected after 8 frying cycles	85.15 ± 0.71^{f}	ND	85.15 ± 0.71^{b}	ND	85.15 ± 0.71^{b}	ND
Oil collected after 16 frying cycles	121.51 ± 1.56^{g}	ND	121.51 ± 1.56^{f}	ND	121.51 ± 1.56^{e}	ND
Oil collected after 24 frying cycles	150.47 ± 0.00^{h}	ND	150.47 ± 0.00^{g}	ND	150.47 ± 0.00^{f}	ND
	Collected after 8 frying cycle		Collected after 16 frying cycle		Collected after 24 frying cycle	
Oil treated with 5% SA	78.61 ± 4.47^{ef}	7.68	103.04 ± 19.13^{de}	15.18	122.71 ± 0.39^{e}	18.45
Oil treated with 15% SA	58.05 ± 0.24^{c}	31.82	92.98 ± 1.23^{c}	23.47	102.59 ± 2.26^{cd}	31.82
Oil treated with 5% CoAS	54.07 ± 3.66^{bc}	36.50	100.98 ± 5.44^{d}	16.89	110.64 ± 4.13^{d}	26.47
Oil treated with 15% CoAS	48.18 ± 0.81^{b}	43.42	87.47 ± 1.62^{b}	28.02	94.20 ± 2.43^{c}	37.40
Oil treated with 5% CoNS	65.95 ± 1.67^{d}	22.55	110.08 ± 4.55^{e}	9.40	127.83 ± 8.31^{e}	15.04
Oil treated with 15% CoNS	59.36 ± 8.70^{bc}	30.28	94.21 ± 0.32^{cd}	22.46	111.51 ± 5.79^{d}	25.89
Oil treated with 5% CoNS + CoAS	75.20 ± 1.51^{e}	11.68	102.68 ± 0.00^{de}	15.49	130.19 ± 5.62^{e}	13.48
Oil treated with 15% CoNS + CoAS	64.51 ± 1.26^{d}	24.24	92.21 ± 1.99^{c}	24.11	99.21 ± 2.64^{c}	34.07

Note: Values are expressed as mean ± SE ($n = 2$). Means in the same column not sharing the same superscripts are significantly different at ($p < 0.05$).
Abbreviations: CoAS, cocoa shells adsorbent; CoNS, coconut shells adsorbent; CoNS + CoAS, mixture of cocoa and coconut shells adsorbent; NI, no improvement; ND, not determined; SA, synthetic adsorbent.

TABLE 7 Hedonic sensory analysis of local doughnuts fried in oils that have been filtered using adsorbents.

	Sensory parameters				
Samples	Colour	Odour	Taste	Texture	Overall acceptability
Fresh oil	7.8 ± 0.31^{b}	7.6 ± 0.11^{b}	8.1 ± 0.33^{b}	7.5 ± 0.00^{c}	7.5 ± 0.21^{a}
Oil untreated after 16 frying cycle	6.5 ± 0.71^{a}	6.7 ± 0.14^{a}	6.9 ± 0.14^{a}	6.1 ± 0.14^{a}	6.7 ± 0.57^{a}
Oil treated with 15% CoAS	6.8 ± 0.42^{a}	6.9 ± 0.14^{a}	6.4 ± 0.42^{a}	7.2 ± 0.14^{c}	7.3 ± 0.28^{a}
Oil treated with 15% CoNS + CoAS	6.9 ± 0.14^{a}	6.8 ± 0.42^{a}	6.5 ± 0.32^{a}	6.7 ± 0.14^{b}	7.1 ± 0.14^{a}

Note: Values are expressed as mean ± SE ($n = 2$). Means in the same column not sharing the same superscripts are significantly different at ($p < 0.05$).
Abbreviations: CoAS, cocoa shells adsorbent; CoNS + CoAS, mixture of cocoa and coconut shells adsorbent.

shows that, based on the sensory parameters evaluated, doughnuts fried in treated oils received higher scores than those fried in oxidised untreated oil. Although no significant difference ($p > 0.05$) was noted, the overall acceptability of doughnuts fried in treated oils (7.3 ± 0.28 and 7.1 ± 0.14) was higher than that of doughnuts fried in untreated oil (6.7 ± 0.57). Nevertheless, the doughnut samples fried in fresh oil were the most popular with consumers. These results suggest that regenerating oils using CoAS and the mixture cocoa–coconut shells would improve the organoleptic properties of fried products.

4 | CONCLUSION

This study has shown that carbonised cocoa and coconut shells are porous activated carbons with polar and nonpolar groups on their surfaces. Using these activated carbons as adsorbents in the filtration of oxidised oils has demonstrated their ability to eliminate primary and secondary oxidation products. These impurities are bound by the functional groups of the activated carbons, thereby improving the hygiene and organoleptic properties of frying oils. The data from this study can be used as a benchmark for the valorisation of these

agricultural by-products in the production of natural adsorbents for oil regeneration.

AUTHOR CONTRIBUTIONS

Gires Boungo Teboukeu: Writing—original draft; methodology; investigation; formal analysis; conceptualization. **Prudent Ngabe Mituga**: Writing—original draft; investigation; formal analysis; data curation. **Ghislain Tazoho Maffo**: Writing—review and editing; methodology; conceptualization; supervision. **Georges Teikam Kenda**: Writing—review and editing; methodology; investigation; formal analysis. **Ronice Zokou**: Investigation; data curation. **Archelle Abaobo Foudjin**: Investigation; data curation. **Hilaire Macaire Womeni**: Writing—review and editing; validation; supervision.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ETHICS STATEMENT

Ethical clearance was obtained from the Regional Committee for Ethics in Human Health Research of the West Region (CRERSH-West) with Project Identification Number: 544/30/04/2025/CE/CRERSH-OU/VP. The authors declare that the participants included in the sensory analysis were not forced to participate in the study and verbal consent was taken from all the participants. Complete disclosure of the study requirement and risks were communicated to the participants. The participants were aware that the data of the participants will not be released without their prior knowledge and they could withdraw from the study at any stage of the study.

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