

Research Article

Mitigating Postfrying Degradation Factors of Fats and Oils through the Development of Bagasse-Based Adsorbent

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The quality of fats and oils is a critical aspect of the food processing industry and consumer health. Fat degradation, particularly through oxidation, impacts various quality parameters, including color, taste, flavor, aroma, quality, and appearance. To address this issue, a study was conducted using five degraded fats/oil (DF/O) commodities as the target for an adsorption process. These commodities were chosen because of their high level of degradation by-products. The study used sugarcane bagasse (SCB) to develop five different treatments of indigenous adsorbents activated with various NaOH concentrations. Analyses including iodine number, adsorbent yield, and scanning electron microscope were performed to identify the potential of the prepared concentrations. Results showed that the indigenous adsorbent created with 1.0% NaOH was the most effective. The alkali treatment had a positive impact on the samples, but the SCB 10% was found to be the most efficient in reducing the degradation value of the treated samples. The findings of this study suggest that the use of indigenous adsorbents, particularly those prepared with SCB 10%, can be an effective way to reduce fat degradation and enhance the quality of fats and oils in the food processing industry. This approach can also address consumer health concerns related to fat and oil quality.

1. Introduction

Cooking oil is used as a heat-conducting medium to alter the physical characteristics and texture of food to impart a savory flavor as well as to increase the food's caloric content and nutritional value. Yellow grease is the term used to describe degraded cooking oil that has been used frequently (used cooking oil). During the frying process, the oil is damaged by oxidation, polymerization, or hydrolysis, which results in the development of unintended carcinogenic chemicals (peroxide and aldehyde) that are hazardous to human health [1].

Due to a rise in demand, Pakistan's cooking oil refining business has grown quickly in recent years, but it has been noted that most industries do not adhere to the standards set

by the Pakistan Standards and Quality Control Authority (PSQCA). According to the study, there were significant differences between the quality of Banaspati ghee sold commercially in Pakistan and the standards established by PSQCA. Therefore, the government must act right away to control the quality of Banaspati ghee [2]. A lot of the Banaspati ghee products contain palm oil, which is mainly composed of 48% saturated fatty acids and 52% unsaturated fatty acids, among which palmitic acid (85%) and oleic acid (88%) are most abundant [3].

Pakistan has been endowed with horticulture soil, which is perfect for growing and manufacturing organic goods [4–7]. Bagasse from sugarcane is an abundant source of cellulose (32–45%), hemicellulose (20–32%), and lignin (17–32%), as well as 1.0–9.0% ash and some organic

components. For many years, the massive production of sugarcane bagasse (SCB) has posed a significant threat to the global economy and environment. The adsorption process has benefits due to its simplicity of use, high capacity for waste treatment, and generally low cost owing to the potential of reuse. However, the high cost of adsorbents is one of the challenges to this method, so alternate sources of inexpensive and effective adsorbents are necessary [8].

There has been a lot of study done on the recovery of frying oils through selective adsorption and the elimination of undesirable polar molecules using active filtration. Degraded frying oil is commercially blended with adsorbent materials, filtered, and collected in the fryer for future use. This technique has been found to extend the life of frying oil by limiting the formation of free fatty acids and total polar materials without impacting the safety or sensory quality of the fried items. Commercial adsorbent products, such as Frypowder, Britesorb™, Magnesol®, and OilFresh™, are available in markets [9]. While these remedies are commercially viable, application at a small scale and vendor level is still necessary to ensure food quality and safety among consumers of street foods. This necessitates the development of a low-cost and easily applicable adsorbent which can be effectively accessed through natural sources.

In this study, an adsorbent made from SCB that has been treated with NaOH was compared to Magnesol XL, a synthetic adsorbent that is frequently used to restore the quality of used and deteriorated fats and oils. The best-performing treatment was additionally put through frying action to test the adsorbent's durability and stability.

2. Materials and Methods

2.1. Development of Indigenous Adsorbent. The indigenous sugarcane bagasse adsorbent (SCBA) was made from SCB using the method reported by Wannahari and Nordin [10]. The bagasse was properly cleaned to remove any dust or unwanted particles. Using a chaff cutter machine, the cleared residue was broken down into smaller stalks. After size reduction, the bagasse was washed again to remove any remaining dirt or sugar particles and then dried for 48 hours to eliminate any moisture. The dried residue was then processed until fine SCB powder was produced in a grinder with a mesh size of 600 μm . This fine SCB was then washed with AquaDes solution and dried at room temperature again. Bagasse was heated in a hot air oven (Memmert, Germany–Model UM 200) for 120 min at 200°C, then activated for 24 hours with different formulations of NaOH solution (0.5, 1.0, 1.5, 2.0, and 2.5%), and then heated for another 1.5 hours. The impregnated mixture was filtered and heated for another 90 min at 200°C and then dried to obtain an activated adsorbent.

2.2. Determination of Activity Level of Various Formulations

2.2.1. Activated Carbon Yield. The activated carbon yield was determined using the following equation, as demonstrated by Xu et al. [11]:

$$\text{yield (\%)} = \frac{(\text{weight of activated carbon})}{(\text{dry weight of precursor})} \times 100. \quad (1)$$

2.2.2. Iodine Number. The activity level of the produced formulations was determined using the ASTM D4607-94 [12] iodine number method.

2.2.3. Scanning Electron Microscope. The structural morphology of the prepared bagasse treatments was analyzed using the method by Schwantes et al. [13] with some modifications. The bagasse and adsorbent particles were coated with Au/Pg (16.38 g/cm³) to a thickness of 8 nm using Cressington Sputter Coater 208 HR (Watford, UK) then observed under Zeiss Crossbeam 350 (Toronto, Canada) up to 50 μm magnification. The micrographs were obtained digitally and zoomed to multiple magnitudes to observe structural profiles of bagasse precursor and prepared adsorbents.

2.2.4. Particle Size Analysis. The particle size analysis of prepared adsorbents was performed using microparticle analyzer (Microtrac MRB Sync, York, USA). Each sample was individually placed onto the microparticle tray, and the apparatus was allowed to run for 60 seconds. The peaks were recorded in MRB software and different size ranges of microparticles were recorded for each adsorbent treatment.

2.3. Treatment of Degraded Fat/Oil Samples. Five treatment levels of SCB precursor (based on w/v percentage of fat/oil) were created through the method explicated by Bhattacharya et al. [14]. For the yield achieved for each subsequent treatment level, an equivalent quantity of Magnesol XL was applied for comparison.

2.3.1. Application of Indigenous Adsorbent (Bagasse) Treatments. Five different samples of degraded fats/oils (DF/Os), which were previously isolated from a batch of 50 degraded frying fats and oil samples [15], were heated to 110°C, and then SBA adsorbent was added and agitated for 1 hour at 500 rpm and 110°C and filtered using Whatman filter paper no. 41 and muslin cloth and was kept in a sealed jar at 4°C [10, 14].

2.3.2. Application of Synthetic Adsorbent (Magnesol XL) Treatments. Magnesol XL as a synthetic adsorbent was combined in assorted concentrations with used frying oil. Stirring for 1 hour at 105°C homogenized the mixture. The homogeneous mixture was then filtered using No. 41 Whatman filter paper (Whatman International Ltd, Maidstone, UK) [16].

2.4. Physicochemical Analysis of Treated Used Frying Fat and Oil Samples. The free fatty acids (FFA) of all the treated samples were determined according to the method

mentioned in AOCS [17] Official Method Ca 5a-40. The peroxide value (PV) was estimated according to AOCS [17] Official Method Cd 8b-90. The oxidative stability index (OSI) was also analyzed by the Rancimat apparatus at the temperature of 110°C according to AOCS [17] Official Method Cd 12b-92.

2.5. Fatty Acid Profile by GC-FID. To examine the impact of an adsorbent on the fatty acid profile of treated samples, the fatty acid profile of all the treated samples was determined as FAME by GC-FID using a fused silica capillary column coupled with an FID as previously described.

2.6. Frying Study. The potato fries were soaked in a 2.5% NaCl solution for 5 min, filtered, and dried using paper napkins before frying. Deep frying (in best selected treatment level oil) of potatoes was carried out for different frying cycles (2, 4, 6, and 8 cycles) in a deep fryer at 130°C for 10 min.

2.6.1. Postfrying Physicochemical Analysis of a Treated Sample. The free fatty acid (FFA), peroxide value (PV), and oxidative stability index (OSI) of all the treated samples were determined according to the method as mentioned in AOCS [17] Official Methods.

2.6.2. Statistical Analysis. The resulted data obtained from various analyses were subjected to one-way and two-way analysis of variance (ANOVA) under completely randomized design (CRD) followed by Tukey's HSD as post hoc analysis through methodology as explicated by Montgomery [18].

3. Results and Discussion

3.1. Activated Carbon Yield. The yield of SCB-based adsorbent after activation is shown in Table 1. A significant decline ($P \leq 0.05$) was observed in SCB adsorbent treatments as the concentration of NaOH was increased. The carbon yields of various concentrations varied between $15.31 \pm 1.32\%$ and $65.31 \pm 3.52\%$. The SCB yield was significantly decreased as the concentration of NaOH was increased among adsorbent treatments. Activated carbon yield is usually reliant upon precursor heating and activation temperature, concentration of alkali with which it is activated, and the time given for activation. Another possibility for increase in yield with respect to decrease NaOH concentration may be due to the hydrogen bonding properties of NaOH crystal which causes its boiling point to increase because of which the NaOH crystals were retained along with sugarcane bagasse biochar and played effective role in total yield. This might also be accounted for by the way that the chemical agent influences the condensation (polymerization) reactions. In the structure of the activated products, these reactions between the aromatic hydrocarbons and tar-forming substances lead to the production of big molecules

TABLE 1: Mean values of adsorbent yield (%) obtained from various SCB treatments.

NaOH concentration (%)	Yield (%)	Adsorption capacity (mg/g)
0.5	65.31 ± 3.52^a	610.55 ± 12.87^{bc}
1.0	43.15 ± 2.76^b	652.79 ± 11.19^a
1.5	38.76 ± 2.32^b	646.33 ± 9.67^a
2.0	19.70 ± 1.16^c	619.43 ± 12.49^b
2.5	15.31 ± 1.32^c	596.33 ± 7.73^c

Means that do not share a letter are significantly different.

(polycyclic aromatics). While studying the development of activated carbon through surface modification with sodium hydroxide using palm kernel shells and coconut shells, Hafizuddin et al. [19] also observed that the yield of NaOH-activated carbon decreased by a significant margin in both coconut shell and palm kernel shell as the concentration of NaOH was increased.

3.2. Adsorption of Iodine. The mean values of results pertaining to iodine adsorption capacity of prepared bagasse treatments are shown in Table 1. The iodine adsorption capacity of bagasse treated with various concentrations ranged between 596.33 ± 7.73 and 652.79 ± 11.19 mg/g of iodine adsorbed. A significant variation ($P \leq 0.05$) was observed among the mean values of formulation treatments. It was observed that iodine number of SCB increased from 610.55 ± 12.87 mg/g at 0.5% alkali concentration to a peak value of 652.79 ± 11.19 mg/g at 1.0% NaOH concentration and then gradually declined as the alkali ratio was further increased. The American Water Works Association (AWWA) recommends a minimum iodine number of 500 mg/g for using activated carbon to remove various waste compounds [20]. It was evident that the alkaline agent and its concentrations influenced the formation of the porous texture during activation. Comparable results were observed by Xu et al. [11] who observed a constant decline in iodine number of NaOH from an average 470 mg/g to 220 mg/g as the NaOH concentration increased from 0.39% to 1.57%, respectively. The decrease in iodine adsorption capacity might be attributed to the fact that at higher impregnation ratios, the pore gets wider than the optimal width and eventually gets burnt off which eventually causes a decline in iodine adsorption capacity. This was speculated by Bedmohata et al. [21] who observed a similar distribution curve with an initial increasing and gradual decreasing pattern while studying the influence of H_3PO_4 on lignin-based activated carbon. This indicates the pyrocatalytic degradation becomes more intense with increase in impregnation ratio.

3.3. Scanning Electron Microscope Analysis. Figures 1(a)–1(f) represent the SEM images of the prepared bagasse-based adsorbents at various magnifications. As shown in Figures 1(a) and 1(b), the raw bagasse sample exhibited rough and flaky surfaces with many small irregular cavities over the surface. When activated

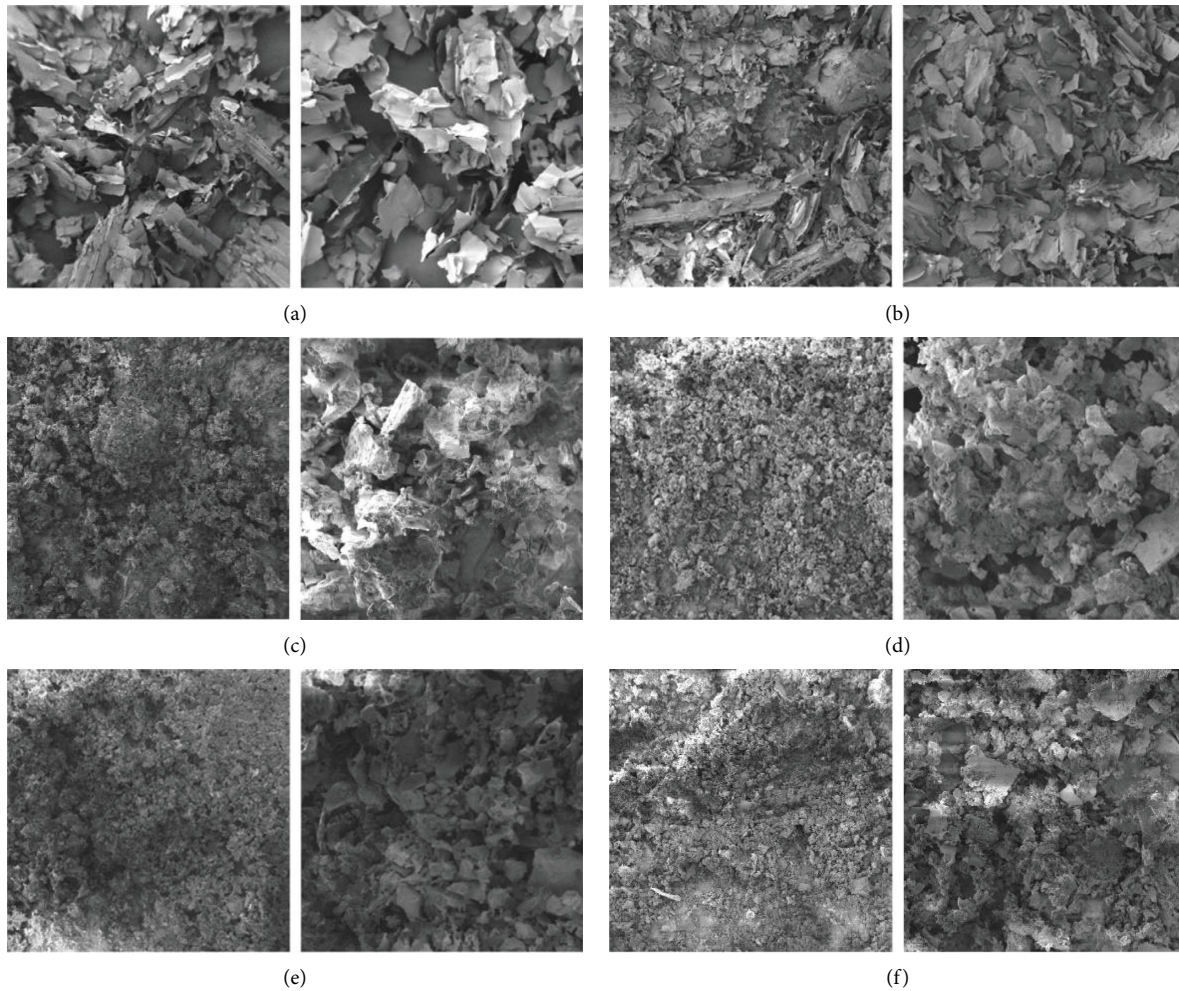


FIGURE 1: SEM micrographs of (a) control SCB precursor, (b) SCB 0.5% NaOH, (c) SCB 1.0% NaOH, (d) SCB 1.5% NaOH, (e) SCB 2.0% NaOH, and (f) SCB 2.5% NaOH at 80 and 500 \times magnifications.

with NaOH, the resulting samples contained open holes and brittle structures, which is why the activated carbon prepared by the NaOH activation was expected to have larger adsorption capacity due to larger surface area and pore size which allows cavities for adsorbing various compounds. Figure 1(a) shows the SEM micrographs of SCB precursor and SCB treated with 0.5% alkali concentration which features elongated and flat-faced, fibrous structures with minor small pores.

As shown in Figures 1(c) and 1(d), it was observed that SCB treated with NaOH 1.0% and 1.5% alkali solution had more visible pores and a granulated appearance. However, SCB treated with 2.0 and 2.5% (Figures 1(e) and 1(f)) of alkali treatment shows visible pores and hollow structures of relatively smaller size which indicates that a significant level of porosity was developed as a result of activation. Degenerative structures were observed in SCB bagasse treated with 2.5% NaOH, indicating that the pyrocatalytic degradation apparently destroyed some of the fibrous structures, resulting in lesser pores over the surface area.

The structures appear heterogeneous, with different-sized particles but with a uniform and filamentous framework. According to observation by Bonassa et al. [22] who studied the effect of SCB ash for waste cooking oil treatment, SCB ash can be heterogeneous with varying portions of macro-, meso-, and micropores, which may contribute to irregularity of structure when seen through microscope. Activated carbon is usually microporous, with a high capacity to adsorb small molecules, such as those present in gases and solvents. It is also necessary to have meso- and macropores for large molecule adsorption, such as waste cooking oil. Similar results were studied by Portero-Barahona et al. [23] where they studied SCB hydrolysis enhancement with various concentrations of NaOH.

3.4. Particle Size. The particle sizes of various concentrations of alkali treated SCB are shown in Table 2 and Supplementary Figures S1–S6. The highest particle size in terms of area distribution was observed for control ($MA = 302.0 \mu\text{m}$) with a volume distribution of $465.8 \mu\text{m}$. The lowest value was

TABLE 2: Mean values of particle size (μm) for various SCB treatments.

SCB (% NaOH)	MV (μm)	MN (μm)	MA (μm)	CS	SD	Mz	σ	Ski	Kg
Control	465.8	72.4	302.0	$1.99E-02$	230.5	440.4	246.1	0.2871	1.225
0.5	376.8	15.92	107.8	$5.60E-02$	325.5	345.2	340.5	0.521	1.197
1.0	281.2	13.47	84.55	$7.10E-02$	223.9	246.7	240.9	0.499	1.187
1.5	116.2	8.47	42.01	$1.43E-01$	95.4	103.3	101.4	0.639	1.304
2.0	99.27	3.65	31.07	$1.93E-01$	78.39	88.01	87.07	0.598	1.595
2.5	80.18	5.86	32.99	$1.82E-01$	67.05	77.66	63.95	0.51	0.89

MV: mean diameter as per volume distribution, MN: mean diameter as per number distribution, MA: mean diameter as per area distribution, SD: standard deviation, Mz: graphic mean (less coarse particles with respect to MV), σ : inclusive graphic standard deviation, Ski: inclusive graphic skewness, and Kg: kurtosis (peakedness) of distribution.

observed for SCB treated with 2.0% NaOH solution with a mean average diameter of $31.07 \mu\text{m}$ and mean volume diameter of $99.27 \mu\text{m}$.

The particle size of the SCB adsorbent was observed to significantly decrease ($P \leq 0.05$) with respect to increase in NaOH concentration. This may be attributed to dissolution of SCB during activation at higher concentrations of NaOH, resulting in finer and hence smaller particle size. The decreasing particle size showed somewhat positive correlation with adsorption efficiency of SCB adsorbent; however, this was not entirely observed during iodine adsorption analysis. This also depends on the activation concentration of alkali. These results are in line with a related study by Song et al. [24] on development of micron-sized magnesium hydroxide using NaOH, where it was also observed that increasing the NaOH concentration from 3.00 mol/L^{-1} to 8.00 mol/L^{-1} decreased the particle of magnesium hydroxide from 27.46 to $22.27 \mu\text{m}$, respectively.

3.5. Selection of Best Suitable Adsorbent Concentration.

Based on the retrieved data, SCB treated with 1.0% and 1.5% concentration of NaOH showed highest affinity and activity levels as most suitable for application purposes; however, bagasse with 1.0% NaOH concentration showed slightly better adsorption capacity. According to Putranti et al. [25], higher concentrations of NaOH can make the solution viscous and the diffusivity of the solution into adsorbent pores can decrease and may cause structural deformation which eventually affects adsorption efficiency, which may be why the SCB adsorbents prepared with 2.0% and 2.5% NaOH activation showed relatively less efficiency in terms of iodine adsorption and surface area analysis through SEM.

3.6. Treatment of Degraded Fats/Oils Samples.

Based on the best selected concentrations (1.0% NaOH), treatment levels of sugarcane bagasse were developed with respect to 5, 10, 15, 20, and 25% w/v ratios with degraded oil samples. The respective weights of sugarcane bagasse were then developed into adsorbents through activation with 1.0% concentration of NaOH; yields obtained were $2.62 \pm 0.12 \text{ g}$ for 5%, $4.25 \pm 0.22 \text{ g}$ for 10%, $7.12 \pm 0.19 \text{ g}$ for 15%, $9.04 \pm 0.27 \text{ g}$ for 20%, and $11.17 \pm 0.83 \text{ g}$ for 25% w/v of treatment levels. Magnesol XL (MXL) was used in the same amount as their respective 5, 10, 15, 20, and 25 w/v % SCB adsorbent

counterparts for respective treatment levels as shown in Table 3.

3.7. Physicochemical Analysis

3.7.1. Free Fatty Acids (FFA). The FFA value of treated oils and fats is shown in Figure 2. As compared to untreated or fried oil, more than 60% FFA reduction was observed in various treated samples. With regards to the effect of indigenous adsorbent, SCB treated with 1.0% NaOH at a w/v ratio of 10% (SCB 10%) showed significant results as compared to SCB ratios added with other w/v ratios. FFAs are carboxylic groups with a polar side, primarily the carboxyl group ($-\text{COOH}$), which is also electropositive. Adsorbents treated with NaOH can help in rendering the adsorbent into a more hydrophilic state which may help in adsorbing polar compounds, which is why FFAs as polar molecules are more attracted to the hydrophilic nature of adsorbent and get adsorbed in higher quantities [25]. The reduction in samples treated with SCB 20% and SCB 25% was slightly lesser as compared to SCB 10 and 15%. The reason may be the oversaturation of SCB adsorbent into the oil which increased the adsorbent to oil ratio and resulted in lesser oil being subjected to adsorption temperature, which may have reformed minor free fatty acid components. Similar results were observed by Wulandari and Dewi [26] while studying the effect of sugarcane bagasse-based nanocellulose on used cooking oil.

3.7.2. Peroxide Value (PV).

A significant reduction in PV was observed using SCB and MXL treatments in all treated samples as shown in Figure 3. The main products of edible fats and oils oxidations are peroxides and hydroperoxides. As a result, peroxide determination can be used as an oxidation index for the initial stages of oil oxidation [16]. A reduction in PV indicates that SCB adsorbent was considerably effective in reducing the PV of the degraded fat and oil samples. This may be explained by the Freundlich isotherm, which considers the heterogeneity of the adsorbent surface and various ions trapped in the adsorbent pores affecting the overall effectivity of the adsorbent. According to Freundlich isotherm-based study of bagasse, it was observed that adsorbents can only adsorbate peroxide ions up to a certain limit and adding more adsorbent weight did not result in more reduction in PV [27].

TABLE 3: Treatment ratio allocation of sugarcane bagasse-based adsorbent and Magnesol.

Sr. no.	Adsorbent	Sugarcane bagasse (w/v %)	Magnesol XL (w/v %) or (other synthetic adsorbents)
1	SCB 5	5 (2.62 ± 0.12 g)	—
2	SCB 10	10 (4.25 ± 0.22 g)	—
3	SCB 15	15 (7.12 ± 0.19 g)	—
4	SCB 20	20 (9.04 ± 0.27 g)	—
5	SCB 25	25 (11.17 ± 0.83 g)	—
6	MXL 5	—	5 (equivalent to SCB 5%)
7	MXL 10	—	10 (equivalent to SCB 10%)
8	MXL 15	—	15 (equivalent to SCB 15%)
9	MXL 20	—	20 (equivalent to SCB 20%)
10	MXL 25	—	25 (equivalent to SCB 25%)

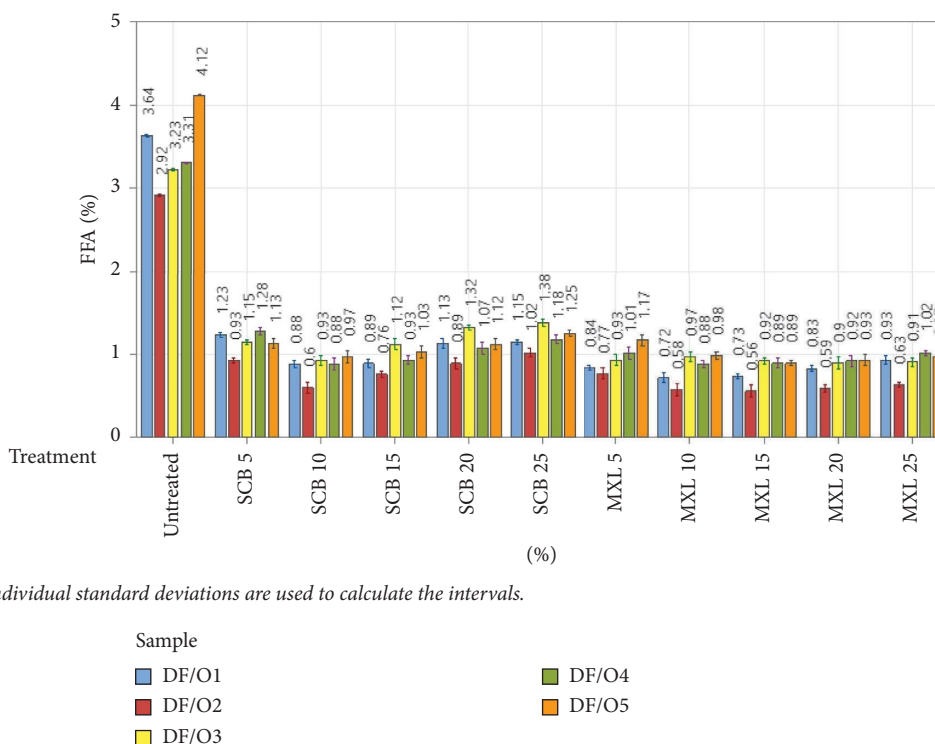
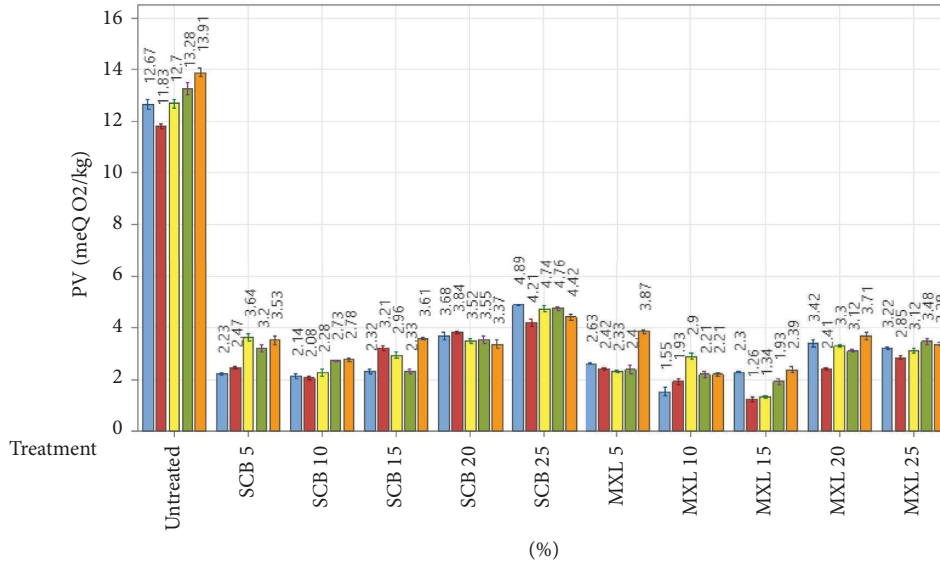


FIGURE 2: Mean values of FFA (%) observed after SCB and MXL treatments of selected degraded edible fats and oils.

3.7.3. Oxidative Stability Index. The oxidative stability index of all samples treated with SCB and MXL is shown in Figure 4. The results revealed that OSI of all samples was moderately enhanced after using MXL treatments. However, only a minor improvement was observed in samples treated with SCB concentrations. Minor reduction in higher SCB concentrations may have been attributed to higher SCB to fat/oil treatment ratio which may have affected various physicochemical factors owing to overconcentration of the adsorbent material, treatment time, and temperature. Similar results were observed by Lin et al. [28] while studying the effect of different filter aids on four different samples of degraded oils with 1, 2, and 3% of Hubersorb, Frypowder, and Magnesol.

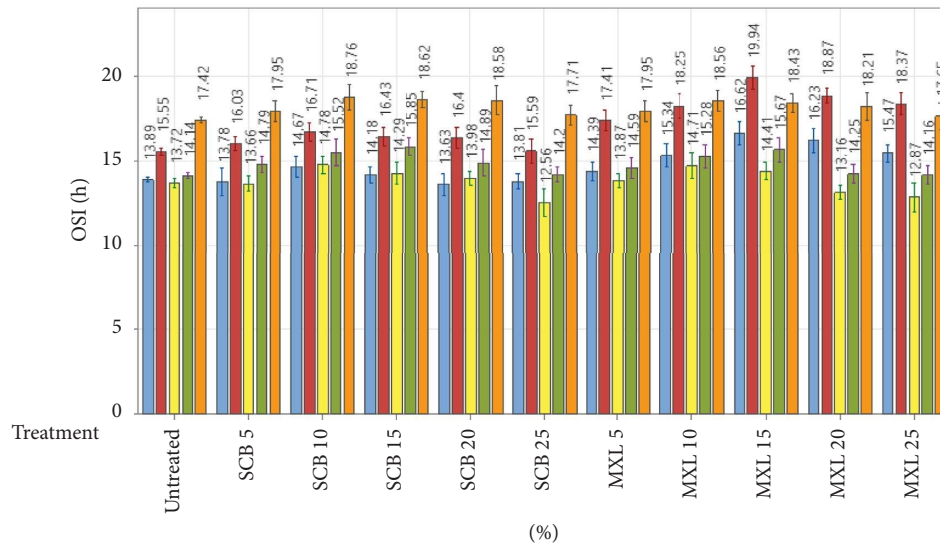
3.7.4. Fatty Acid Profile. The fatty acid profile results can be observed from Supplementary Tables S1–S5. The results revealed negligible changes in TFA contents of the treated fat and oil samples with minor exceptions. According to Konkol et al. [29], the cis/trans-isomerization of oleic and linoleic acid is practically irreversible, which may be the reason why the TFAs were not significantly affected after treatment with various concentration levels of both SCB and MXL. In some cases, a negligible reduction in trans-9-elaidic acid and linolelaidic acid levels was observed in lower concentrations of both SCB and MXL in most treatments which may have been due to removal of other total polar compounds in the treated oil. On the contrary, a minor increase in trans-9-elaidic acid and linolelaidic acid was observed in some



Individual standard deviations are used to calculate the intervals.



FIGURE 3: Mean values of PV (mEq O₂/kg) observed after SCB and MXL treatments of selected degraded edible fats and oils.



Individual standard deviations are used to calculate the intervals.



FIGURE 4: Mean values of OSI (h) observed after SCB and MXL treatments of selected degraded edible fats and oils.

treated samples. Comparatively lower weight to volume ration of oil with adsorbent material was applied at higher concentrations (20% and 25%) of SCB and MXL which may have caused a higher exposure of adsorption temperature

towards the oil and contributed to elevated temperature, leading to a partial effect on trans-fatty acid levels. Some of the samples were observed to have particular variation in peak values and minor retention times, which could be due

TABLE 4: Physicochemical and oil stability analyses parameters of the best selected treatment (DF/O₂) after 2, 4, 6, and 8 frying cycles.

DF/O ₂	Frying cycles				
Analysis parameter	0 frying	2 nd frying	4 th frying	6 th frying	8 th frying
FFA (%)	0.60 ± 0.03 ^e	0.76 ± 0.02 ^d	0.88 ± 0.03 ^c	1.02 ± 0.05 ^b	1.16 ± 0.04 ^a
PV (mEq O ₂ /kg)	2.08 ± 0.12 ^c	2.98 ± 0.15 ^d	3.59 ± 0.25 ^c	4.74 ± 0.32 ^b	6.53 ± 0.14 ^a
OSI (h)	16.71 ± 0.94 ^c	14.52 ± 0.28 ^c	13.06 ± 0.32 ^c	12.79 ± 0.21 ^b	12.28 ± 0.16 ^a

Means that do not share a letter are significantly different.

to numerous factors influencing separation (and/or retention times) in gas chromatography, such as column form, sample concentration, temperature conditions, and carrier gas flow rate. A dilute sample allows for sufficient stationary-mobile phase equilibrium within the column, resulting in narrow Gaussian-shaped peaks, and variation in dilution value can cause changes in retention time and peak value observations [30]. A similar investigation was conducted on the effects of hydrothermally treated SCBA on the adsorption of capric and oleic acid in soybean oil. Oleic acid and capric acid had adsorption capabilities of 11.6 and 78.8 mg/g at an acid concentration of 0.50% and 62.3 and 90.3 mg/g at an acid concentration of 1.00%, respectively [31].

3.7.5. Selection of Best Treatment Level of Adsorbent. After careful physicochemical and rheological analyses and studying the structures of all the treated fats and oils, the samples treated with SCB 10% were observed to have optimal values for most quality parameters specifically peroxide and free fatty acid values. As compared to higher concentrations of the 1.0% NaOH treated SCB, 10% w/v treatment showed a significant reduction of PV and FFA. The w/v ratios for SCB 5% may have presented lesser available adsorbent material and hence showed relatively lesser potential for enhancement of physicochemical properties in degraded fats and oil samples upon application. Increasing the w/v ratio by more than 10% was observed to have a declining effect on the adsorption efficiency and rejuvenation of selected oil samples which may be attributed to higher adsorbent to oil ratio and temperature conditions associated with the adsorption process. Among the oil samples, DF/O₂ showed overall better results and enhancement capability as compared to other oils. Therefore, oil sample DF/O₂ treated with SCB 10% was selected for further analysis proceeding to the frying application using French fries as a development commodity.

3.8. Analysis of Best Adsorbent Treated Oil after Frying Cycles. After the application of frying treatment including frying cycles, individual analyses of samples after each consecutive frying of 2, 4, 6, and 8 frying cycles were observed.

3.8.1. Free Fatty Acids. FFA value of best selected oil after application of frying cycles can be seen in Table 4. As shown in the table, the FFA value was observed to increase from 0.60 ± 0.03% in treated and stable state but gradually increased to 0.76 ± 0.02% after two frying cycles and eventually

reached up to 1.16 ± 0.04% after the 8th frying cycle. As previously stated, oil degradation and triglyceride hydrolysis contribute to a rise in FFA content. Since in this case, the fat sample has been previously degraded and revitalized using adsorption process, the rise in FFA content may have been abrupt as compared to fresh fat or oil. Similar changes were observed by Patel et al. [32], who studied the frying cycle behavior as a result of deep fat frying in ghee samples treated with various herbs and spices. A gradual rise in FFA was observed from 0.2% to 0.45% after 5 consequent frying cycles.

3.8.2. Peroxide Value. Application of frying cycles had a significant effect on PV of selected treatment oil as shown in Table 4. The PV peaked at 6.53 ± 0.14 mEq/kg at the 8th frying cycle. Intermittent frying at high temperatures speeds up the oxidation and polymerization processes, raising the PV and degrading the oil or fat quality. Similar results were observed by Kaur et al. [33] where PV of various oil samples showed a highly significant increasing trend of PV over a series of 10 frying cycles.

3.8.3. Oxidative Stability Index. As shown in Table 4, the oxidative stability showed reduced changes as a result of increased frying activity. The OSI of the treated oil sample declined from an induction time of 16.71 ± 0.94 h to 12.28 ± 0.16 h throughout 8 frying cycles. Temperature fluctuations alter the oxidation mechanism and produce hydroperoxides, which function as precursors to volatile odors and oil or fat breakdown. Due to the exponential increase in oxidation rate with a rise in temperature, fat and oil shelf life typically decreases at high heat levels, as was the case in the indigenous adsorbent treated fat sample where the oxidative stability decreased steadily over the frying period. According to Tabasum et al. [34], while studying the quality characteristics of ghee samples in variously treated samples, OSI was observed to reduce in samples.

Based on the observed values, the replenished oil showed stable value for consistent frying up to the 4th frying cycle after which the deterioration rate increased significantly, which may be attributed to its continuous frying use before adsorbent treatment and other factors including storage interval passed between sample collection, pretreatment, chromatography profiling, and adsorption and posttreatment analyses. Nonetheless, the safe value for SCB 10% treated postadsorption usage of moderately degraded frying oil is up to four frying cycles which can vary in other conditions.

4. Conclusion

The selected SCB-based indigenous adsorbent activated with 1.0% NaOH along with synthetic adsorbent, namely, Magnesol XL, was used to treat the preselected degraded fat and oil samples with five different weights by volume solution ratios. Most of the treated samples responded positively to the solution ratios; however, SCB 10% was found to have a comparatively significant reduction in the degradation value of treated samples. Among the treated samples, DF/O₂ was observed to show relatively better reduction in FFA, PV, and OSI. However, a minor reduction in multiple treatments was observed throughout the adsorption process. The DF/O₂ sample was further subjected to the frying application using French fries as a frying commodity for up to 8 frying cycles, whereby the SCB 10% treated sample was tested for physicochemical and oxidative stability characteristics after every two cycles. Based on the observed values, the replenished oil had stable values for consistent frying up to the 4th frying cycle after which the deterioration rate gradually increased. Nonetheless, the SCB 10% treated commodity showed optimal stability in terms of retaining its physicochemical and oxidative stability parameters. The results of this study show that filtration of used frying oils with various concentrations of sugarcane bagasse-based adsorbent somewhat improved their quality and had similar adsorbing properties to synthetic adsorbents in eliminating oil oxidation products. If this technology is used at the commercial and market level, it can benefit both vendors and customers by reducing the propensity for fats and oils to degrade and improving health standards in diverse worldwide populations that rely on and are accustomed to consuming deep-fried foods. Sugarcane bagasse created as an adsorbent can contribute to this goal due to its extremely flexible nature and adsorbing characteristics, which can aid in the removal of a variety of pollutants from foods, particularly fats and oils. More research is needed to explore more into the adsorption potential of sugarcane bagasse, particularly in terms of mitigating degradation elements from used food fats and oils. This creates opportunities for future study, which could lead to the discovery of new uses and improve the efficiency of SCB-based adsorbents in diverse food industry scenarios. The usage of SCB-based adsorbents may offer an environmentally friendly alternative for preserving the quality of frying oils in restaurants, fast-food chains, and other culinary establishments. This not only opens the door to further scientific investigation, but it also offers possible breakthroughs in practical applications within the broader culinary business.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Waqar Ahmed wrote the original draft, was responsible for statistical design, and contributed to software analysis and graphics. Muhammad Asim Shabbir visualized and supervised the study, proposed the methodology, and provided the resources. Rana Muhammad Aadil supervised the study, provided the resources, and reviewed and edited the article. Muhammad Anjum Zia provided the resources and reviewed and edited the article. Anubhav Pratap-Singh provided the resources and reviewed and edited the article.

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Supplementary Materials

Supplementary Figure S1: particle size distribution of control SCB precursor represented in microns (μm). Supplementary Figure S2: particle size distribution of SCB 0.5% represented in microns (μm). Supplementary Figure S3: particle size distribution of SCB 1.0% represented in microns (μm). Supplementary Figure S4: particle size distribution of SCB 1.5% represented in microns (μm). Supplementary Figure S5: particle size distribution of SCB 2.0% represented in microns (μm). Supplementary Figure S6: particle size distribution of SCB 2.5% represented in microns (μm). Supplementary Table S1: fatty acid profile of A2 treated with SCB 5–25% and MXL 5–25%. Supplementary Table S2: fatty acid profile of D2 treated with SCB 5–25% and MXL 5–25%. Supplementary Table S3: fatty acid profile of M2 treated with SCB 5–25% and MXL 5–25%. Supplementary Table S4: fatty acid profile of N2 treated with SCB 5–25% and MXL 5–25%. Supplementary Table S5: fatty acid profile of Y₁ treated with SCB 5–25% and MXL 5–25%. (*Supplementary Materials*)

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