

Application of Chemically Modified *Pinctada Imbricata Radiata* Shell Waste as a Potential Sustainable Odour-Control Material for Refrigerated Fish Storage

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ABSTRACT

The sustainable valorization of marine processing residues has emerged as an important strategy for supporting circular bioeconomy principles while reducing environmental burdens associated with shell waste disposal. In this study, waste shells of *Pinctada imbricata radiata* were chemically modified using phosphoric acid and combined with commercial activated carbon to produce a composite adsorbent intended for odour mitigation during refrigerated fish storage. The material was evaluated using treated SAT and CHT and untreated control SAC and CHC samples of *Sparus aurata* and *Clupea harengus*, stored at 1–3 °C for 12 days.

Odour evolution was assessed by a sensory panel of 15 untrained adolescent participants aged 15–17 years using a structured five-parameter questionnaire evaluating odour intensity, odour characteristics, foreign odours, potential odour transfer, and overall sensory acceptability. Statistical analysis was performed using one-way ANOVA followed by Tukey's post hoc test $p < 0.05$ for stage-specific comparisons. Treated samples generally exhibited lower sensory odour deterioration compared with untreated controls, particularly during the later stages of refrigerated storage. The greatest improvement was observed in CHT, which maintained lower odour intensity, reduced development of undesirable odours, and higher sensory acceptability throughout storage compared with CHC. Similarly, SAT exhibited a more favourable sensory odour profile relative to SAC, although spoilage-related odour changes progressed more rapidly than in the *Clupea harengus* samples.

These differences should be interpreted in relation to the distinct characteristics of the two fish matrices, since the *Sparus aurata* and *Clupea harengus* samples differed in origin and processing condition. These findings indicate the potential of the developed shell-derived composite as an odour-control material under the specific experimental conditions investigated. However, the present study does not establish microbial inhibition, extension of microbiological shelf life, or the identity and concentration of the volatile compounds affected by the treatment. In addition, the contribution of the individual composite components and the effect of adsorbent dosage were not independently investigated.

Keywords: *Pinctada imbricata radiata* shell waste; marine by-products valorization; circular bioeconomy; chemically modified adsorbent; activated carbon composite; volatile organic compounds adsorption; odour mitigation; sustainable food preservation.

INTRODUCTION

The Blue Economy seeks to achieve economic growth while ensuring environmental protection, through appropriate policies and strategies for the management of marine resources [1]. Pearl oysters consist of approximately 60 % shell and 40 % soft tissues, which are usually discarded after pearl harvesting. The

transformation of these by-products into innovative, high value-added products would increase economic benefit and reduce environmental impact [2]. As a large-scale waste material, bivalve mollusc shells, which are rich in calcium carbonate CaCO_3 , present significant potential for utilisation in sectors such as the construction materials industry, agriculture for soil improvement, environmental restoration, and the development of innovative high-tech materials [3]. After appropriate processing, which includes washing, grinding, sieving, and heat treatment, bivalve shells can be used as effective adsorbent materials for the removal of pollutants from aquatic environments. Their high adsorption capacity towards various contaminants, including toxic metals, makes them suitable for environmental remediation applications and the protection of aquatic ecosystems. Thus, from low-value waste materials, they are transformed into innovative materials of high added value [4,5].

By-products from aquaculture and fisheries can be reused rather than discarded, within the framework of the circular economy and the Blue Growth strategy, contributing to the sustainable management of resources and consequently to the sustainable development of enterprises [6]. Activated carbons are produced from a variety of organic materials which undergo physical or chemical activation through pyrolysis or chemical impregnation. These processes lead to the development of materials with highly porous structures and an extensive pore network [7,8]. Activated carbon is typically produced from carbon-rich raw materials such as coconut shells, wood, agricultural residues, and industrial by-products, through pyrolysis and chemical activation processes [7,9]. Volatile organic compounds VOCs, which arise from microbial and biochemical processes during food storage and processing, can be used to assess freshness and microbial contamination [10].

Activated carbons are widely used as adsorbent media for odour control, owing to their highly developed porous structure. Their ability to adsorb volatile organic compounds VOCs, which are key contributors to odour formation, makes them one of the most widely used technologies for odour reduction in applications related to industrial sectors such as the food industry [11]. The presence of free amino acids and microorganisms with decarboxylase activity promotes the formation of biogenic amines in fishery products. These compounds are important indicators of microbial spoilage, quality, and safety of seafood, with histamine being considered the most significant biogenic amine due to its association with cases of food poisoning [12].

Seafood products may develop unpleasant off-odours due to microbial activity, environmental conditions, and processing or storage practices, affecting their quality and commercial value. Earthy and musty odours are mainly associated with compounds such as geosmin and 2-methylisoborneol 2-MIB, which are produced by aquatic microorganisms such as cyanobacteria and actinomycetes, and can accumulate in fish tissues. For freshness assessment, rapid methods such as electronic nose E-nose systems have been developed, offering faster evaluation compared to conventional analytical techniques. However, classical methods present limitations in terms of speed and on-site applicability, highlighting the need for simpler and more immediate quality control tools [13].

The investigation of odours through questionnaires represents a simple and cost-effective approach, which does not require technical equipment and facilitates the understanding of consumer perceptions and preferences [14,15]. Within this framework, the present study examines the potential utilization of *Pinctada imbricata radiata* shell waste through chemical activation with H_3PO_4 , with the aim of modifying the surface characteristics of the shell-derived material, and its combination with commercial activated carbon to produce a composite adsorbent. The 1:1 mass ratio of modified shell material to activated carbon was selected as a fixed formulation for this preliminary investigation and was not intended to represent an optimized composition or a recommended practical formulation. The proposed composite was evaluated with respect to its potential to mitigate the sensory development of undesirable odours during the refrigerated storage of fish.

The sensory evaluation was conducted using questionnaires, through which participants' subjective perceptions regarding odour quality were recorded at specific time intervals. The sensory panel consisted of 15 untrained adolescents aged 15–17 years, and the evaluation was conducted without formal panel training or calibration. The assessment of pleasant odour characteristics was carried out on days 2, 4, and 6, whereas the evaluation of the development of unpleasant odours was performed on days 8, 10, and 12. The study was designed as a preliminary proof-of-concept evaluation of the potential odour-control performance of the developed composite

under refrigerated storage conditions. Accordingly, the results should be interpreted as sensory evidence of odour mitigation rather than definitive evidence of food preservation. Importantly, because no physicochemical characterization of the developed material and no instrumental volatile-compound analysis were performed, the present study does not directly demonstrate changes in surface properties or confirm adsorption of specific VOCs.

MATERIALS AND METHODS

Materials Procurement and Experimental Materials

In the present study, waste shells of *Pinctada imbricata radiata* were investigated as a marine-derived raw material for the preparation of a shell-based functional adsorbent material. A total amount of 1 kg of shell waste was collected from locally available marine processing residues. Commercial activated carbon, with a total mass of 500 g, was obtained from a local supplier in Messolonghi, Greece, and was used as an additional adsorbent component for the preparation of the composite material. Two fish species with different storage characteristics and commercial relevance were selected for the evaluation of odour mitigation performance. Samples of *Sparus aurata* were obtained from a commercial aquaculture facility, while Atlantic *Clupea harengus* was obtained as a commercially available marinated product in brine from a local supermarket. These two products were therefore not considered chemically or technologically equivalent fish matrices, and comparisons between species were interpreted cautiously. Differences in salt content, processing history, initial quality, and matrix composition may have influenced odour development during storage. Phosphoric acid with a purity of 95–97% and deionised water were used during the chemical modification process. The experimental groups were coded according to fish species and treatment condition as follows: SAT treated *Sparus aurata*, SAC untreated control *Sparus aurata*, CHT treated *Clupea harengus*, and CHC untreated control *Clupea harengus*. Treated samples contained the developed composite adsorbent material, whereas control samples were stored under identical conditions without adsorbent addition. The experimental design did not include separate groups containing shell-derived material alone or commercial activated carbon alone. The experimental design did not include separate groups containing shell-derived material alone or commercial activated carbon alone.

Preparation of Shell-Derived Material

The shells of *Pinctada imbricata radiata* were initially washed thoroughly with deionised water to remove adhered organic residues, surface contaminants, and particulate impurities. The cleaned shells were subsequently dried in a conventional oven at 100 °C for 24 h until complete removal of moisture. The dried shell material was mechanically ground using a high-speed electric mill and subsequently sieved through a stainless-steel sieve with a mesh opening of 100 µm in order to obtain a uniform particle size fraction. The resulting powdered shell-derived material was stored in sealed containers under dry and shaded conditions at room temperature until chemical modification.

Chemical Modification of Shell-Derived Material

Chemical modification of the shell-derived material was performed using phosphoric acid as a surface-treatment step intended to alter the physicochemical characteristics of the shell material. A quantity of 500 g of powdered shell material was treated with 500 ml of 1 M phosphoric acid solution. The treatment was performed at room temperature for 30 min under static conditions without mechanical agitation. After completion of the chemical modification process, the treated material was separated by filtration and repeatedly washed with deionised water until the filtrate reached neutral pH. This step was performed to ensure the removal of residual soluble acid from the modified shell-derived material. The resulting material was dried in an oven at 100 °C for 24 h and stored under dry conditions until preparation of the composite adsorbent material. No instrumental characterization was performed to experimentally verify changes in surface area, pore structure, morphology, functional groups, mineral phases, or surface chemistry following phosphoric acid treatment. Therefore, any effect of the chemical treatment on the adsorption-related properties of the shell-derived material remains unverified in the present study.

Preparation of Composite Adsorbent Material

The composite adsorbent material was prepared by combining the chemically modified shell-derived material obtained from *Pinctada imbricata radiata* with commercial activated carbon. The two components were mixed at an equal mass ratio 1:1, w/w to formulate the composite adsorbent incorporating both components. This 1:1 ratio represented a fixed experimental formulation selected for preliminary screening and was not established through optimization or comparative testing of alternative ratios. No systematic comparison of alternative shell-to-activated-carbon ratios was performed in the present study. The mixture was transferred into the grinding chamber and mechanically milled for 2 min to ensure homogeneous distribution of the two components and improve material uniformity. The final composite adsorbent was collected and stored in sealed containers under dry and shaded conditions at room temperature until application in fish storage experiments.

Experimental Design and Fish Storage Conditions

The experimental design was established to evaluate the effect of the developed composite adsorbent material on sensory odour evolution during refrigerated storage of different fish products. For each fish product, treated and untreated control groups were prepared under identical storage conditions. Samples of *Sparus aurata* and *Clupea harengus* were filleted and divided into portions with a mass of 100 ± 1 g. Each portion was placed in a food-grade polypropylene container with a capacity of 600 ml equipped with an airtight lid. The closed storage system was designed to minimise external contamination and allow controlled accumulation of volatile compounds released during storage. A handmade wooden support was positioned inside each container to maintain physical separation between the fish sample and the adsorbent material. This arrangement prevented direct contact between the fish tissue and the adsorbent while allowing interaction between the released volatile compounds and the material surface. For the treated groups, 100 g of the composite adsorbent material was placed at the bottom of each container, while the corresponding fish sample was positioned above the material on the wooden support. For the control groups, the same storage procedure was followed without the addition of adsorbent material. The resulting adsorbent-to-fish mass ratio was approximately 1:1. This relatively high adsorbent-to-fish ratio was used as an experimental screening condition and should not be interpreted as a commercially optimized or recommended dosage. The effect of lower adsorbent dosages and the economic feasibility of the selected ratio were not investigated. The experimental groups were designated according to fish species and treatment condition. The samples were stored under refrigerated conditions at 1–3 °C for a total period of 12 days, and sensory evaluations were conducted at predefined storage intervals.

Sensory Evaluation of Odour Development During Refrigerated Storage

The sensory evaluation was performed to assess the evolution of odour characteristics during refrigerated storage and to compare the performance of treated and untreated samples. The sensory panel consisted of 15 participants, including 10 males and 5 females, aged between 15 and 17 years. All participants were adolescents and untrained sensory panelists. All participants were healthy and reported no known olfactory impairments. The evaluation was conducted using individual structured questionnaires, allowing each participant to independently record their sensory perception. The questionnaire included five evaluation parameters related to odour intensity, odour characterisation, development of foreign or unusual odours, potential odour transfer effects, and acceptability based exclusively on odour perception. Each parameter was evaluated using a five-point scoring system presented in Table 1. The panel was composed of untrained participants and was therefore treated as a consumer-type exploratory sensory panel rather than a trained descriptive panel. No formal sensory training or calibration procedure was performed. Blinding and randomization procedures were not incorporated into the original experimental design. These methodological limitations may have introduced the potential for subjective or expectation-related effects and should therefore be considered when interpreting the sensory results. Sensory measurements were conducted on storage days 2, 4, 6, 8, 10, and 12 in order to monitor changes during both the early and advanced stages of refrigerated storage. The sensory results therefore reflect subjective odour perception and should not be interpreted as direct measurements of microbial load, chemical spoilage, or microbiological shelf life.

Statistical Analysis

The experimental data were analysed using IBM SPSS Statistics software. For each storage period, one-way analysis of variance ANOVA was performed to determine differences between treated and untreated control groups. The analysis was conducted separately for each storage day and fish product, with treatment condition as the comparison factor. The assumptions of normality and homogeneity of variance were evaluated prior to statistical analysis. When significant differences were detected, Tukey's honestly significant difference HSD test was applied for multiple comparisons between mean values. Differences were considered statistically significant when the probability value was lower than 0.05. The present statistical analysis was considered exploratory, with the reported comparisons interpreted as storage-stage-specific differences.



Fig. 1. Schematic representation of *Pinctada imbricata radiata* shell waste processing and preparation of the composite material for odour-control applications.

Table 1. Odour Sensory Evaluation Questionnaire

Question Score	5	4	3	2	1
Question1: Odor intensity level	Very strong	Strong	Mild	Very mild	None
Question2: Odor characterization	Rotten / decomposed	Sour / unpleasant	Mildly sour	Slightly fishy	Fresh (clean, natural)
Question3: Foreign or unusual smells	Very intense	Intense	Moderate	Slight	None
Question4: Effect on other foods if stored together	Definitely (high risk)	Likely	Moderate	Slightly	Not at all
Question5: Acceptable for consumption (based on smell only)	No	Probably not	Neutral / uncertain	Probably yes	Yes, absolutely

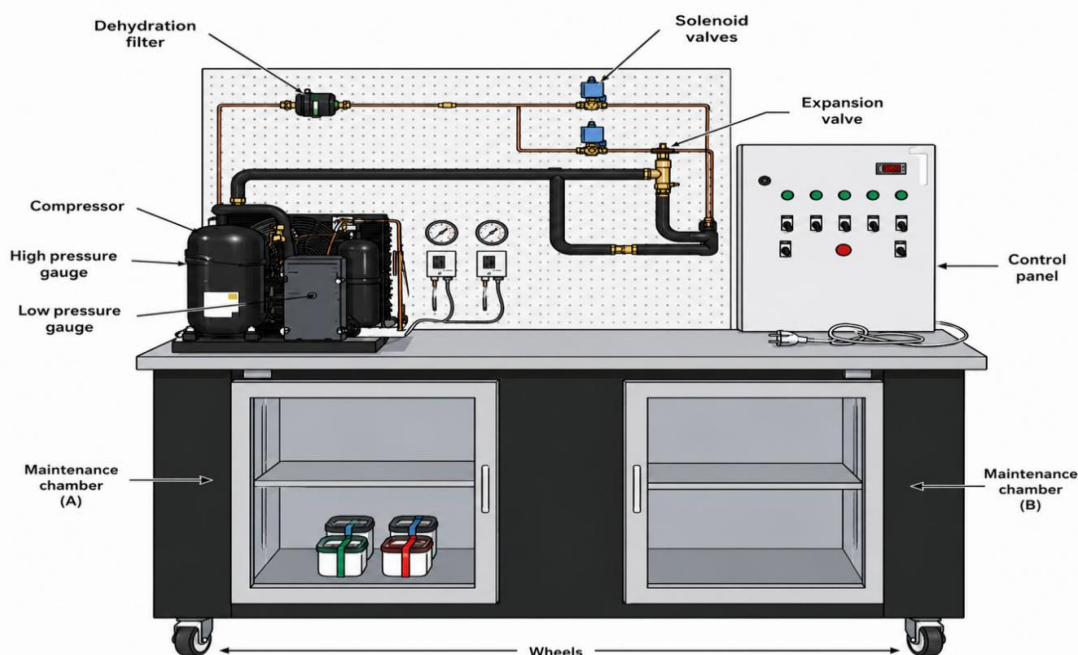


Fig. 2. Refrigerated storage unit used for storage of samples throughout the odour testing process.

RESULTS

The sensory assessment revealed differences in the pattern of odour evolution between treated and untreated samples during refrigerated storage. Across all evaluated parameters, the incorporation of the developed composite adsorbent was associated with delayed development of undesirable odour characteristics, particularly during the later stages of storage. The magnitude of this effect varied according to fish species, with *Clupea harengus* CHT samples showing a slower sensory deterioration pattern than the corresponding untreated CHC samples, while a different and more pronounced deterioration pattern was observed for *Sparus aurata* SAT and SAC samples. Because the two fish products differed in origin and processing history, comparisons between species should be interpreted cautiously. Regarding odour intensity, Tables 2–3 and Figure 3, all samples showed low scores during the first six days of storage, indicating minimal perceived odour development. After day 8, untreated samples exhibited a more pronounced increase compared with treated samples. In particular, CHC reached a final mean score of 2.67 on day 12, whereas CHT remained lower at 2.07. A similar but more pronounced trend was observed in *Sparus aurata* samples, where the untreated SAC samples reached the maximum score of 5.00, while the treated SAT samples showed a lower final mean intensity score of 3.73. These differences indicate a delayed increase in perceived odour intensity in the treated samples.

However, the sensory results alone indicate differences in perceived odour intensity and should not be interpreted as direct evidence of inhibition of spoilage or extension of microbiological shelf-life. The evaluation of odour characteristics, Tables 4–5 and Figure 4, followed a similar pattern. CHT maintained a predominantly fresh odour profile until the final storage stage, whereas CHC showed a gradual transition towards slightly fishy and mildly sour characteristics. In contrast, SAC exhibited rapid sensory deterioration, reaching the rotten/decomposed category by day 12, while SAT showed comparatively less pronounced deterioration. The observed differences suggest that the presence of the developed composite adsorbent was associated with a slower progression of perceived odour changes under the conditions investigated. The statistical comparisons for this parameter were likewise conducted separately for each storage day, and the corresponding significant differences are indicated by superscript letters in Tables 4 and 5.

Nevertheless, these observations describe sensory responses and do not establish which specific volatile compounds were affected or whether the treatment altered the underlying spoilage processes. Foreign odour development and potential cross-odour transfer, Tables 6–9 and Figures 5–6, increased progressively with storage time in all samples. However, treated *Clupea harengus* CHT samples exhibited lower final scores than their corresponding untreated CHC samples, whereas the difference between SAT and SAC became more

evident after day 8. These results indicate that the sensory effect associated with treatment became more apparent during the advanced stages of storage. For these parameters, statistical comparisons were also performed on a storage-day basis, with statistically significant differences identified by different superscript letters in Tables 6–9 $p < 0.05$. Sensory acceptability, Tables 10–11 and Figure 7, demonstrated the same overall trend. Treated samples maintained higher acceptability scores compared with untreated controls, with CHT showing the most favourable overall sensory response. Conversely, SAC exhibited the greatest decline, reaching the lowest acceptability level at the end of storage. The corresponding stage-specific statistical comparisons are presented in Tables 10 and 11, with different superscript letters denoting significant differences between samples within the same storage day $p < 0.05$.

Taken together, the sensory parameters showed a broadly consistent pattern in which the treated samples generally presented lower perceived odour deterioration and higher sensory acceptability than their corresponding untreated controls. These findings represent stage-specific statistical comparisons and should not be interpreted as evidence of a statistically tested interaction between treatment, storage time, and fish product, because such multifactorial interaction effects were not evaluated in the present analysis.

The present results therefore support a preliminary sensory odour-control effect rather than a demonstrated food-preservation or shelf-life-extending effect. No conclusion can be drawn from the present sensory data regarding the identity, concentration, or adsorption of specific volatile organic compounds. The individual panelist responses are retained as supporting data in the Supplementary Materials, while the main Results section emphasizes the corresponding summary statistics mean $\pm$ SD and statistical comparisons.

Where statistically significant differences were identified, these are indicated in the corresponding tables by superscript lettering $p < 0.05$. Because the statistical analysis was conducted separately for each storage day, these comparisons describe differences at individual storage stages and do not constitute a test of overall treatment-by-time or treatment-by-product interactions.

Table 2. High School Students Recorded Responses to Question 1 of the Olfactory Evaluation of SA With and Without Adsorbent Material

STORAGE DAY	SAT	SAC
2	1.00 $\pm$ 0.00 ^a	1.07 $\pm$ 0.26 ^a
4	1.13 $\pm$ 0.35 ^a	1.27 $\pm$ 0.46 ^a
6	1.33 $\pm$ 0.49 ^a	1.47 $\pm$ 0.52 ^a
8	2.67 $\pm$ 0.49 ^b	3.53 $\pm$ 0.52 ^c
10	3.47 $\pm$ 1.06 ^{bc}	3.73 $\pm$ 0.46 ^c
12	3.47 $\pm$ 1.06 ^{bc}	5.00 $\pm$ 0.00 ^d

Note: Values are presented as mean $\pm$ standard deviation (SD). Different superscript letters within the same storage day indicate statistically significant differences among samples according to Tukey’s post hoc test ($p < 0.05$).

Table 3. High School Students Recorded Responses to Question 1 of the Olfactory Evaluation of CH With and Without Adsorbent Material

STORAGE DAY	CHT	CHC
2	1.00 $\pm$ 0.00 ^a	1.00 $\pm$ 0.00 ^a
4	1.00 $\pm$ 0.00 ^a	1.00 $\pm$ 0.00 ^a
6	1.20 $\pm$ 0.41 ^a	1.27 $\pm$ 0.46 ^a
8	1.67 $\pm$ 0.49 ^b	2.20 $\pm$ 0.68 ^c
10	1.87 $\pm$ 0.83 ^b	2.33 $\pm$ 0.72 ^c
12	2.07 $\pm$ 0.26 ^b	2.67 $\pm$ 0.98 ^c

Note: Values are presented as mean $\pm$ standard deviation (SD). Different superscript letters within the same storage day indicate statistically significant differences among samples according to Tukey's post hoc test ($p < 0.05$).

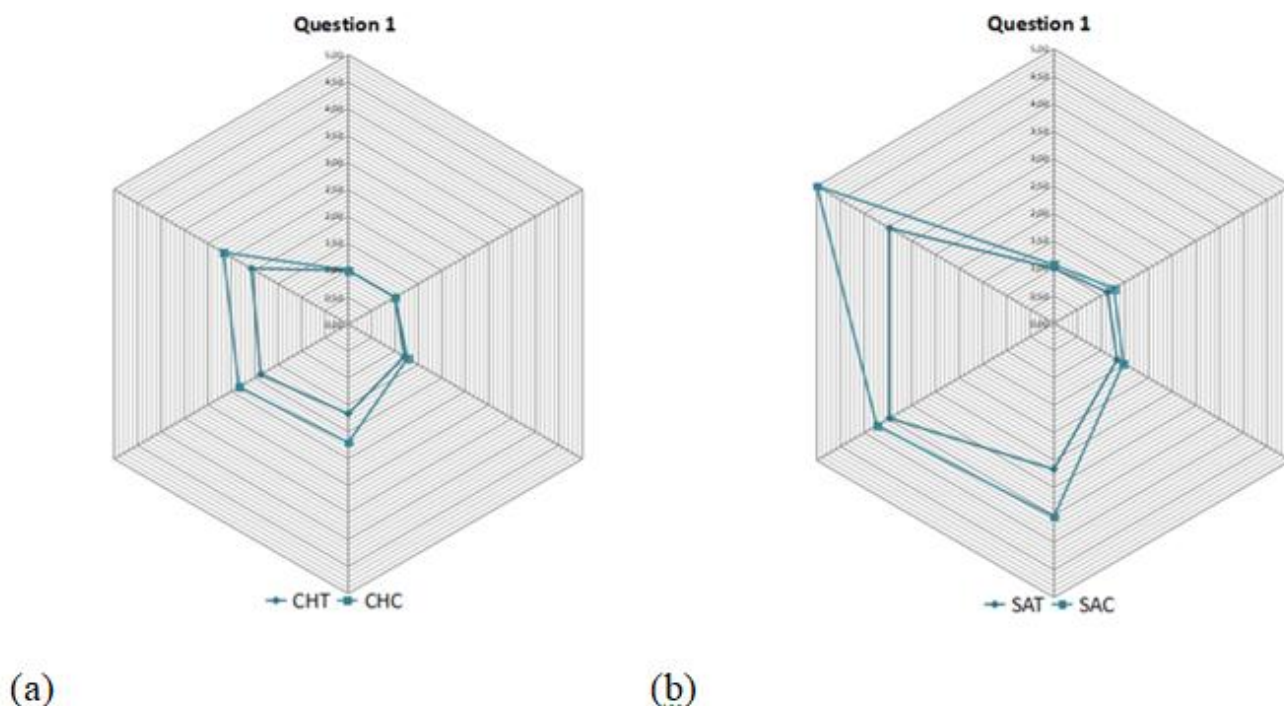


Figure 3. Question 1: Odour Intensity Level During Storage 2–12 Days (a) CHT and CHC Samples, (b) SAT and SAC Samples.

Table 4. High School Students Recorded Responses to Question 2 of the Olfactory Evaluation of SA With and Without Adsorbent Material

STORAGE DAY	SAT	SAC
2	1.00 $\pm$ 0.00 ^a	1.13 $\pm$ 0.35 ^a
4	1.07 $\pm$ 0.26 ^a	1.20 $\pm$ 0.41 ^a
6	1.13 $\pm$ 0.35 ^a	1.27 $\pm$ 0.46 ^a
8	2.33 $\pm$ 1.29 ^b	2.40 $\pm$ 0.91 ^b
10	2.93 $\pm$ 0.96 ^c	3.07 $\pm$ 1.03 ^c
12	3.27 $\pm$ 1.39 ^c	5.00 $\pm$ 0.00 ^d

Note: Values are presented as mean $\pm$ standard deviation (SD). Different superscript letters within the same storage day indicate statistically significant differences among samples according to Tukey's post hoc test ($p < 0.05$).

Table 5. High School Students Recorded Responses to Question 2 of the Olfactory Evaluation of CH With and Without Adsorbent Material

STORAGE DAY	CHT	CHC
2	1.00 $\pm$ 0.00 ^a	1.00 $\pm$ 0.00 ^a
4	1.00 $\pm$ 0.00 ^a	1.07 $\pm$ 0.26 ^a
6	1.00 $\pm$ 0.00 ^a	1.13 $\pm$ 0.35 ^a
8	1.93 $\pm$ 0.26 ^b	2.20 $\pm$ 0.77 ^b
10	2.00 $\pm$ 0.93 ^b	2.07 $\pm$ 1.44 ^b
12	2.07 $\pm$ 0.26 ^b	2.40 $\pm$ 0.51 ^b

Note: Values are presented as mean $\pm$ standard deviation (SD). Different superscript letters within the same storage day indicate statistically significant differences among samples according to Tukey's post hoc test ($p < 0.05$).

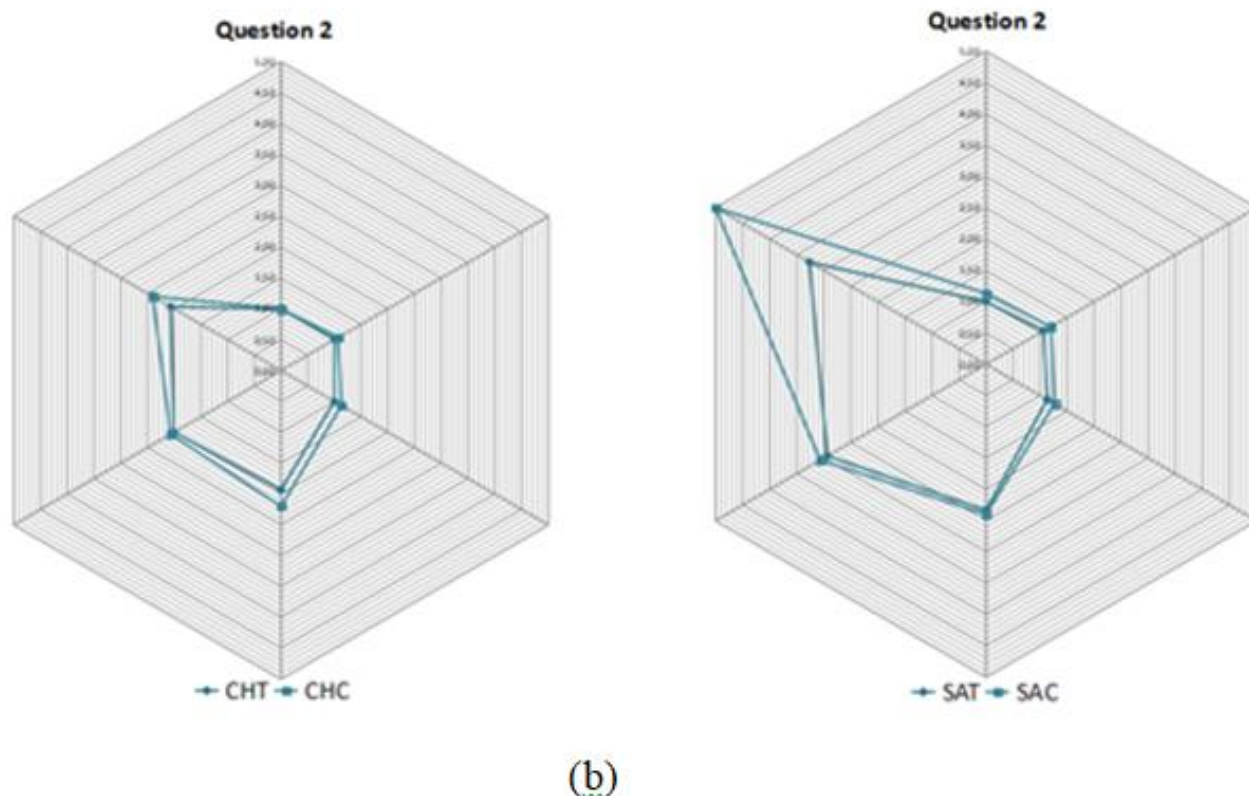


Figure 4. Question 2: Odour Characterization During Storage 2–12 Days (a) CHT and CHC Samples, (b) SAT and SAC Samples.

Table 6. High School Students Recorded Responses to Question 3 of the Olfactory Evaluation of SA With and Without Adsorbent Material

STORAGE DAY	SAT	SAC
2	1.13 $\pm$ 0.35 ^a	1.20 $\pm$ 0.41 ^a
4	1.20 $\pm$ 0.41 ^a	1.27 $\pm$ 0.46 ^a
6	1.33 $\pm$ 0.49 ^a	1.40 $\pm$ 0.51 ^a
8	1.87 $\pm$ 1.51 ^b	2.27 $\pm$ 0.59 ^b
10	2.40 $\pm$ 0.91 ^b	2.47 $\pm$ 1.13 ^b
12	2.93 $\pm$ 1.33 ^c	3.67 $\pm$ 1.95 ^c

Note: Values are presented as mean $\pm$ standard deviation (SD). Different superscript letters within the same storage day indicate statistically significant differences among samples according to Tukey's post hoc test ($p < 0.05$).

Table 7. High School Students Recorded Responses to Question 3 of the Olfactory Evaluation of CH With and Without Adsorbent Material

STORAGE DAY	CHT	CHC
2	1.00 $\pm$ 0.00 ^a	1.00 $\pm$ 0.00 ^a
4	1.13 $\pm$ 0.35 ^a	1.20 $\pm$ 0.41 ^a
6	1.20 $\pm$ 0.41 ^a	1.27 $\pm$ 0.46 ^{ab}

8	1.33 ± 1.05^{ab}	1.73 ± 0.46^b
10	1.47 ± 0.64^{ab}	2.40 ± 1.06^b
12	1.93 ± 0.46^b	2.87 ± 1.41^b

Note: Values are presented as mean $\pm$ standard deviation (SD). Different superscript letters within the same storage day indicate statistically significant differences among samples according to Tukey's post hoc test ($p < 0.05$).

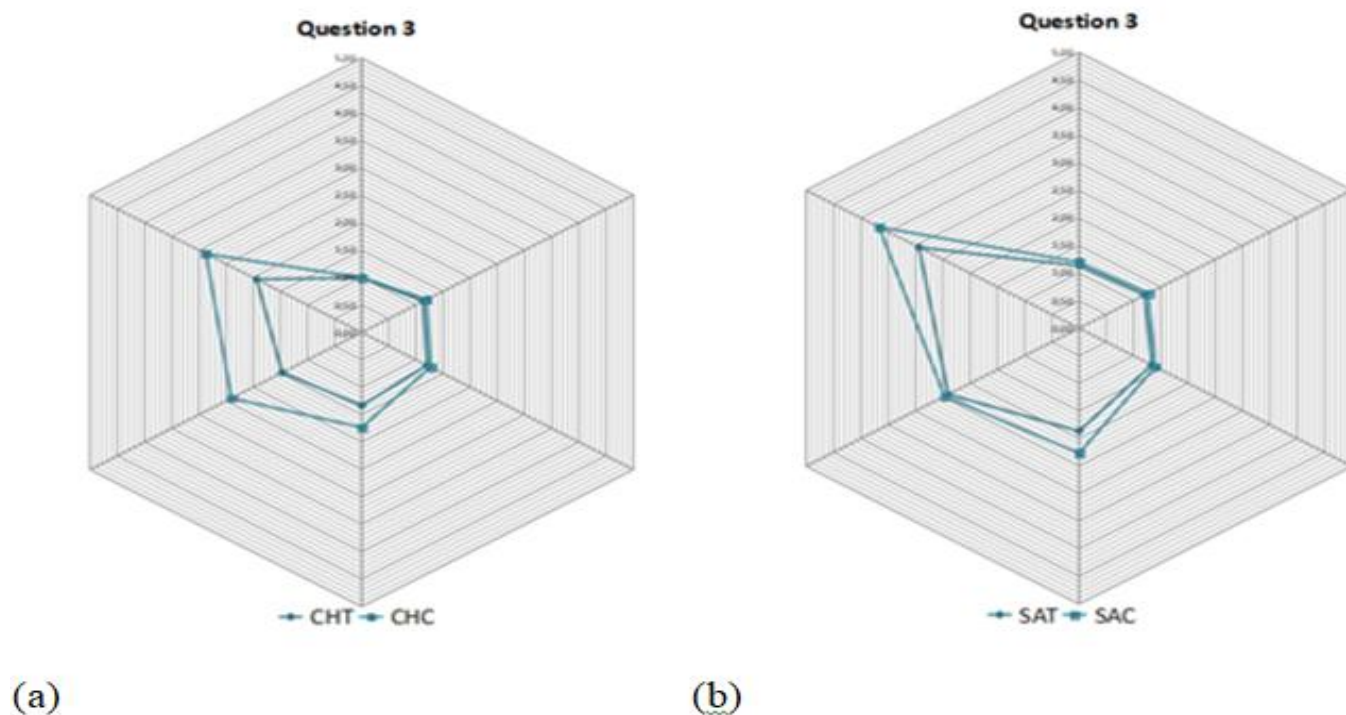


Figure 5. Question 3: Foreign or Unusual Odours During Storage 2–12 Days (a) CHT and CHC Samples, (b) SAT and SAC Samples.

Table 8. High School Students Recorded Responses to Question 4 of the Olfactory Evaluation of SA With and Without Adsorbent Material

STORAGE DAY	SAT	SAC
2	1.00 ± 0.00^d	1.00 ± 0.00^d
4	1.13 ± 0.35^d	1.27 ± 0.46^d
6	1.20 ± 0.41^d	1.33 ± 0.49^d
8	2.73 ± 0.46^c	2.80 ± 0.41^c
10	3.53 ± 0.83^b	3.73 ± 1.10^b
12	3.93 ± 0.46^b	4.80 ± 0.41^a

Note: Values are presented as mean $\pm$ standard deviation (SD). Different superscript letters within the same storage day indicate statistically significant differences among samples according to Tukey's post hoc test ($p < 0.05$).

Table 9. High School Students Recorded Responses to Question 4 of the Olfactory Evaluation of CH With and Without Adsorbent Material

STORAGE DAY	CHT	CHC
2	1.07 ± 0.26^a	1.27 ± 0.46^b
4	1.27 ± 0.46^b	1.33 ± 0.49^b
6	1.40 ± 0.51^b	1.47 ± 0.52^b

8	1.73 ± 0.46^c	1.93 ± 1.10^c
10	1.87 ± 0.52^c	2.13 ± 0.74^{bc}
12	2.00 ± 0.38^{bc}	2.53 ± 1.60^c

Note: Values are presented as mean $\pm$ standard deviation (SD). Different superscript letters within the same storage day indicate statistically significant differences among samples according to Tukey's post hoc test ($p < 0.05$).

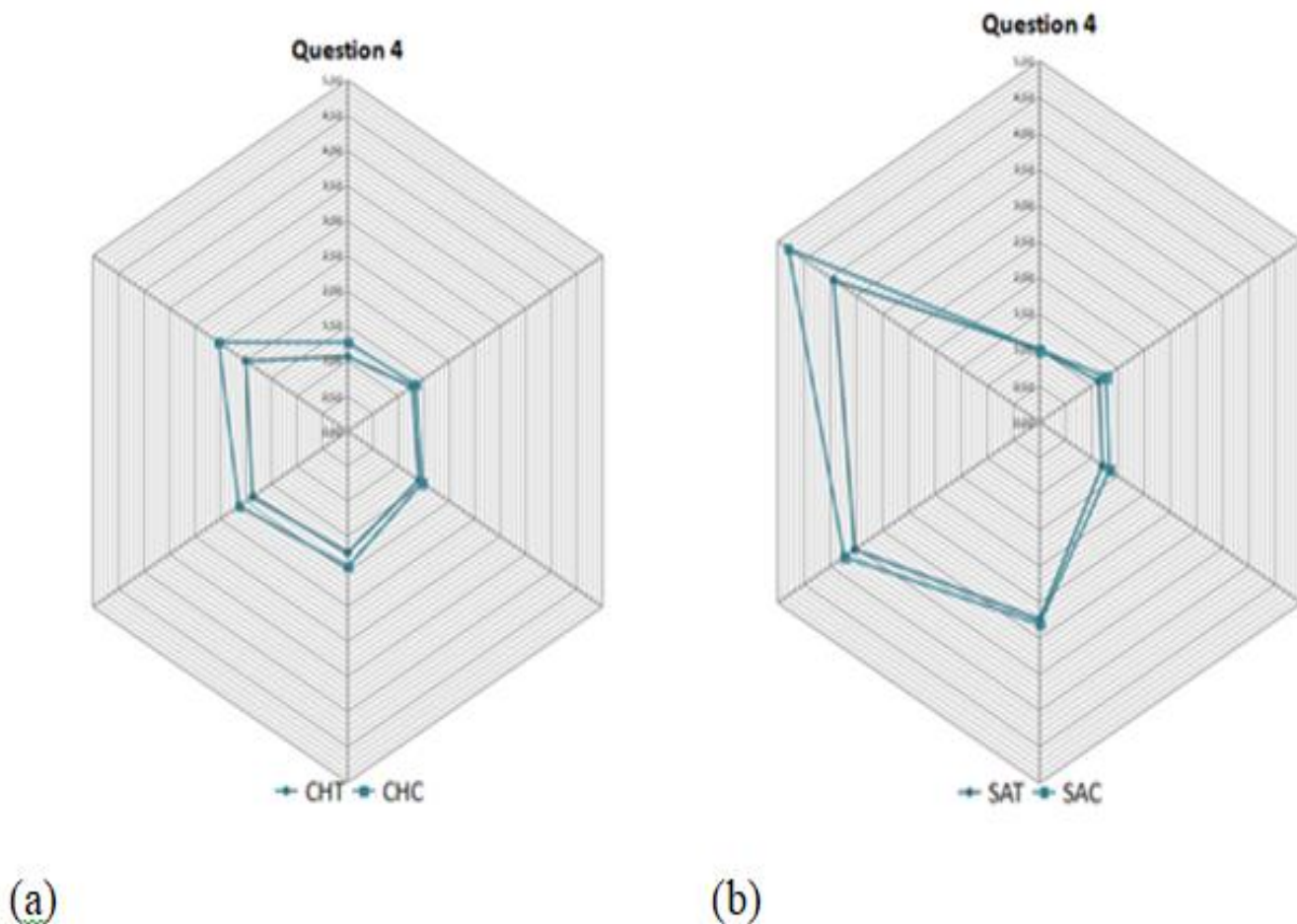


Figure 6. Question 4: Effect on Other Stored Foods During Storage 2–12 Days (a) CHT and CHC Samples, (b) SAT and SAC Samples.

Table 10. High School Students Recorded Responses to Question 5 of the Olfactory Evaluation of SA With and Without Adsorbent Material

STORAGE DAY	SAT	SAC
2	1.07 ± 0.26^a	1.20 ± 0.41^a
4	1.07 ± 0.26^a	1.33 ± 0.49^a
6	1.13 ± 0.35^a	1.47 ± 0.52^a
8	1.73 ± 0.46^{ad}	2.80 ± 1.57^{bc}
10	2.53 ± 0.99^{bd}	3.93 ± 0.46^e
12	3.53 ± 1.13^{ce}	5.00 ± 0.00^f

Note: Values are presented as mean $\pm$ standard deviation (SD). Different superscript letters within the same storage day indicate statistically significant differences among samples according to Tukey's post hoc test ($p < 0.05$).

Table 11. High School Students Recorded Responses to Question 5 of the Olfactory Evaluation of CH With and Without Adsorbent Material

STORAGE DAY	CHT	CHC
2	1.27 ± 0.46 ^a	1.33 ± 0.49 ^a
4	1.40 ± 0.51 ^a	1.53 ± 0.52 ^a
6	1.67 ± 0.49 ^a	1.80 ± 1.01 ^a
8	2.00 ± 0.38 ^{ab}	2.73 ± 0.80 ^b
10	2.27 ± 0.46 ^b	3.07 ± 0.26 ^c
12	2.60 ± 1.06 ^b	3.53 ± 0.64 ^c

Note: Values are presented as mean ± standard deviation (SD). Different superscript letters within the same storage day indicate statistically significant differences among samples according to Tukey's post hoc test ($p < 0.05$).

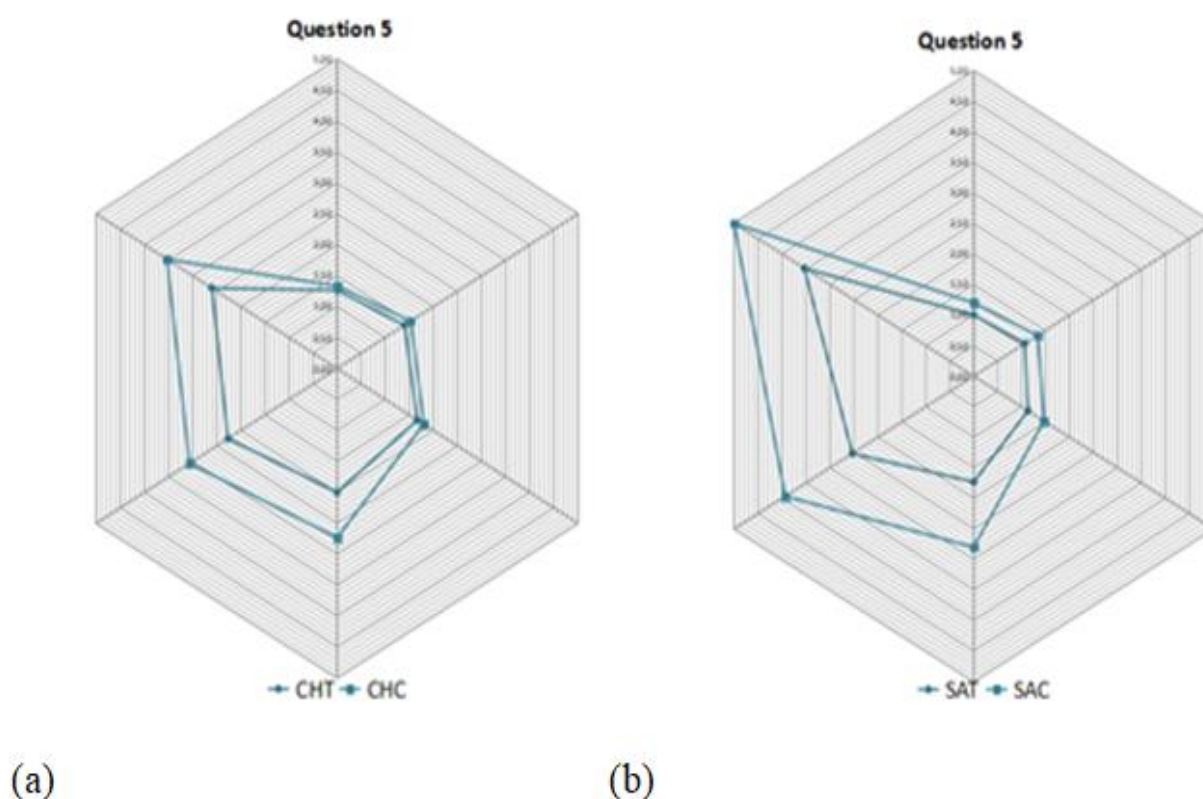


Figure 7. Question 5: Overall Odour Acceptability During Storage 2–12 Days (a) CHT and CHC Samples, (b) SAT and SAC Samples.

DISCUSSION

The present study was designed as an application-oriented investigation evaluating the odour-control performance of a composite adsorbent prepared from chemically modified *Pinctada imbricata radiata* shell material and commercial activated carbon during refrigerated fish storage. In the following discussion, CHT and CHC refer to *Clupea harengus* samples stored with and without the developed composite adsorbent, respectively, whereas SAT and SAC refer to *Sparus aurata* samples stored with and without the treatment. The main objective was to assess whether chemically activated *Pinctada imbricata radiata* shell waste could be incorporated into a composite material showing potential for reducing undesirable odour development during refrigerated fish storage. The main finding of the present study is that, in the stage-specific comparisons performed using one-way ANOVA and Tukey's post hoc test, the complete composite formulation was

associated with improved sensory odour profiles compared with the corresponding untreated controls under the specific storage conditions investigated. Based on the sensory evaluation results, the treated samples generally exhibited improved odour profiles compared with their corresponding untreated controls, with the CHT treatment showing the most favourable performance throughout storage. The lower odour intensity, reduced development of undesirable odour characteristics, and higher sensory acceptability observed in CHT-treated samples indicate that the developed composite adsorbent was associated with improved sensory odour-control performance under the investigated storage conditions. However, these findings should not be interpreted as evidence of confirmed food preservation, microbial inhibition, or shelf-life extension, because no microbiological, physicochemical, or instrumental volatile-compound measurements were performed. The observed differences among fish products may be attributed to the intrinsic characteristics of each food matrix, which can influence biochemical changes and odour development during storage [16,17].

In particular, the present comparison should be interpreted with caution because the two products were not equivalent experimental matrices. *Sparus aurata* was obtained as a fresh aquaculture fish, whereas *Clupea harengus* was evaluated as a marinated product. Differences in salt content, processing history, initial quality, moisture conditions, lipid composition, and other matrix characteristics may therefore have contributed to the observed differences in sensory behaviour. Consequently, the present data do not allow the effect of fish species to be separated from the effect of product formulation and processing history. Among the tested samples, CHT exhibited the most favourable sensory behaviour, maintaining lower odour intensity, reduced foreign odour development, and higher acceptability throughout the storage period. In contrast, SAC samples demonstrated the most pronounced sensory deterioration, reaching the highest odour scores and the lowest acceptability at the end of storage. These observations demonstrate a difference between the complete composite treatment and the corresponding untreated controls, but they do not establish which component of the composite was responsible for the observed sensory effect. These observations confirm differences between the tested treatment and control conditions, but they do not permit attribution of the effect specifically to the chemically modified shell component, to the commercial activated carbon, or to a synergistic interaction between the two components.

This limitation is important because the developed adsorbent contained both phosphoric-acid-modified shell material and commercial activated carbon, while shell material alone and activated carbon alone were not included as independent experimental groups. Accordingly, the current study cannot determine whether the shell-derived fraction itself was responsible for the observed sensory effect, whether commercial activated carbon made the major contribution, or whether the two components acted synergistically. The interpretation should therefore remain focused on the performance of the complete composite formulation rather than on the individual contribution of its components. Future experiments should include at least an untreated control, modified shell material alone, commercial activated carbon alone, and the composite formulation to resolve the relative contribution of each component.

The composite was prepared using a 1:1 mass ratio of modified shell material to activated carbon. Although this formulation produced the sensory responses reported here, the present study does not establish that the 1:1 ratio is optimal. No systematic comparison of alternative shell-to-carbon ratios was performed. Therefore, the observed performance should be regarded as that of the specific formulation investigated rather than as evidence of an optimized composition. Future work should evaluate a range of composition ratios to determine whether changes in the relative amounts of the two components influence odour-control performance. A further limitation concerns the amount of adsorbent applied. The experimental system used approximately 100 g of composite material per 100 g of fish, corresponding to an adsorbent-to-food mass ratio of approximately 1:1. This relatively high dosage may be appropriate for an initial laboratory feasibility assessment but cannot be assumed to be directly transferable to practical food-storage applications.

The present study did not evaluate dose-response behaviour, minimum effective dosage, material consumption, regeneration potential, or economic feasibility. Consequently, the practical scalability of the proposed application remains to be established. The differences observed between *Clupea harengus* and *Sparus aurata* samples further demonstrate the importance of considering the characteristics of the stored food matrix when evaluating waste-derived functional materials. Variations in fish composition and spoilage behaviour, including differences in lipid oxidation susceptibility, microbial development, and the formation of volatile odour-related

compounds, are well-established factors affecting sensory deterioration during refrigerated fish storage [18,19]. These differences may contribute to the different sensory responses observed during refrigerated storage. However, because the products also differed in processing conditions, the present study cannot determine which individual matrix characteristics were responsible for the observed differences. The more pronounced deterioration observed in *Sparus aurata* samples may therefore reflect differences in both product composition and processing history rather than fish species alone.

The observed treatment-associated differences should therefore be interpreted as evidence of a sensory response to the complete composite formulation under the specific experimental conditions, rather than as evidence that chemically modified shell material alone produced the observed effect. The superior performance of CHT was particularly evident during the later stages of storage, when untreated CHC and SAC control samples exhibited higher odour intensity and lower sensory acceptability compared with CHT and SAT, respectively. However, the mechanisms responsible for this behaviour cannot be confirmed solely through sensory evaluation. The observed effects may be associated with adsorption-related interactions between the material surface and volatile compounds generated during storage, including the retention of odour-related molecules. Similar mechanisms have been reported for porous carbonaceous materials and activated carbon-based adsorbents used for the removal of VOCs and odorous compounds [20,21]. In the present study, however, such adsorption-related mechanisms remain hypothetical because no direct instrumental analysis of volatile compounds and no physicochemical characterization of the composite material were performed.

Further analytical investigations are required to clarify whether the observed improvements are mainly related to volatile compound retention, changes in compound distribution, or other physicochemical interactions occurring within the storage system. The absence of direct material characterization also prevents confirmation of changes in surface area, pore structure, morphology, or chemical functionality resulting from phosphoric-acid treatment. Accordingly, the present sensory results cannot be used to demonstrate that phosphoric-acid modification increased the adsorption capacity of the shell-derived material. This distinction is important because the term “chemical activation” may otherwise imply a demonstrated improvement in adsorption performance, whereas the present study evaluated the material primarily through its application in a sensory storage system. From a sustainability perspective, this study provides preliminary evidence for the feasibility of investigating *Pinctada imbricata radiata* shell waste as a feedstock for a value-added functional material. The conversion of marine processing residues into value-added and functional materials represents an emerging circular economy strategy for reducing waste generation and recovering valuable resources from seafood by-products [22]. The conversion of *Pinctada imbricata radiata* shell residues into a functional material is conceptually consistent with circular-economy and waste-valorisation principles, potentially reducing dependence on conventional raw materials. Similar waste valorisation strategies have been investigated for seafood processing residues, including the production of adsorbents, calcium-based materials, and other functional products [23]. Nevertheless, the present study does not provide a quantitative life-cycle, environmental, energy, or economic assessment, and therefore the sustainability advantage of the proposed material cannot yet be demonstrated quantitatively.

The sustainability interpretation should therefore be regarded as a prospective benefit rather than a demonstrated environmental advantage. Although further environmental and economic assessments are required, the proposed approach highlights the potential of redirecting marine processing residues from disposal pathways towards innovative applications with added value. This strategy may contribute to the broader concept of integrating waste valorisation with sustainable food-preservation technologies. However, the present findings should be regarded as a preliminary proof-of-concept for sensory odour management rather than as evidence of a validated food-preservation technology. It should be acknowledged that the present study represents an initial application-based assessment and does not include detailed physicochemical characterization of the produced material. Advanced characterization approaches, including surface area analysis by nitrogen adsorption BET, pore structure evaluation, microscopy techniques SEM/TEM, and spectroscopic analyses FTIR and XPS, are widely used to investigate the surface morphology, porosity, chemical composition, and functional properties of biomass-derived carbonaceous materials [24].

Such characterization would be particularly important in future work to determine whether the chemical modification and subsequent incorporation of the shell-derived material into the composite produced measurable changes in material properties. In addition, instrumental volatile-compound analysis, such as GC-MS, together with microbiological measurements including total viable bacterial counts TVC and physicochemical quality indicators such as total volatile basic nitrogen TVB-N, would be required to determine whether the observed sensory differences correspond to measurable changes in spoilage progression. Furthermore, the sensory evaluation itself represents an important methodological limitation. The panel consisted of 15 untrained participants, and the present study did not include detailed information on formal panel calibration, training, blinding procedures, or independent replication of the sensory experiment.

Accordingly, the sensory results should be interpreted as preliminary consumer-type sensory observations rather than as a fully validated trained-panel assessment. This limitation should be considered when interpreting the magnitude and generalizability of the observed treatment-associated sensory differences. Future studies should incorporate a larger and appropriately characterized panel, standardized sensory protocols, blinded sample presentation, randomization, and independent experimental replicates to improve the reliability and reproducibility of the sensory measurements. In addition, future experimental designs should include independent treatment replicates rather than relying only on repeated sensory evaluations of the same experimental units. Another limitation concerns the statistical analysis. The experimental design included at least fish product, treatment condition, and storage time as relevant factors. Because the present analysis relied primarily on one-way ANOVA, potential interactions among treatment, product type, and storage time were not formally evaluated. Therefore, the current statistical approach is sufficient only for the specific stage-specific comparisons undertaken, but it does not fully characterize the multifactorial structure of the experiment.

A multifactorial statistical model, such as a two-way or three-way ANOVA or an appropriate mixed-effects model accounting for repeated sensory measurements where applicable, would provide a more robust evaluation of treatment effects and their interactions with product type and storage time. Accordingly, the statistical findings should be interpreted as exploratory, stage-specific comparisons rather than as evidence of statistically confirmed interactions among treatment, storage time, and fish-product type. For the same reason, the results should not be framed as demonstrating a universal treatment effect across all storage stages and fish products. The present findings indicate a treatment-associated sensory pattern under the specific experimental conditions tested, but the magnitude and statistical significance of this effect should be interpreted in relation to the individual product matrix and storage time. Overall, the results suggest that the investigated composite formulation has potential as an odour-control material under the specific refrigerated storage conditions evaluated. However, the evidence currently supports a preliminary sensory odour-control effect rather than a confirmed preservation mechanism or shelf-life extension.

The main contribution of the present study is therefore the demonstration of the feasibility of converting *Pinctada imbricata radiata* shell waste into a functional composite material for odour-control applications in refrigerated fish storage, rather than the development of a fully optimized commercial adsorption material or a validated food-preservation technology. Several important questions regarding material properties, component contributions, dosage optimization, statistical interactions, mechanism, microbiological effects, and practical scalability remain to be addressed.

Future studies should focus on clarifying the relationship between material characteristics and sensory performance by investigating the effects of activation conditions, shell-to-carbon composition ratios, individual material components, and adsorbent dosage on volatile compound retention and odour-control efficiency. The integration of physicochemical characterization and adsorption-related measurements represents a widely applied strategy for establishing structure–function relationships in functional adsorbent materials and for understanding the factors determining their performance [26]. Taken together, these approaches would allow future studies to determine whether the sensory effects observed here are associated with measurable changes in volatile compounds, spoilage indicators, and material properties, thereby establishing a stronger structure–function relationship for the proposed shell-derived composite.

CONCLUSIONS

- The composite functional material containing chemically modified *Pinctada imbricata radiata* shell-derived material and commercial activated carbon showed preliminary potential for reducing perceived odour deterioration during refrigerated fish storage under the specific conditions investigated.
- Sensory evaluation showed that treated samples generally exhibited lower odour intensity, reduced development of undesirable odour characteristics, and higher sensory acceptability compared with untreated controls. These findings should be interpreted as sensory effects and not as direct evidence of microbial spoilage inhibition or shelf-life extension.
- The CHT treatment exhibited the most favourable overall sensory performance, providing better perceived odour control during extended storage, particularly after day 8.
- The sensory response varied between the tested fish products, indicating that the interaction between the adsorbent formulation and the characteristics of the food matrix may influence odour-control performance. Because the two products differed in processing history and composition, this observation cannot be attributed to fish species alone.
- The lower sensory deterioration observed in treated samples suggests that the composite formulation may be associated with reduced perception of odour-related changes during storage. However, the proposed mechanism involving adsorption or retention of volatile compounds remains unconfirmed in the absence of instrumental chemical analysis and physicochemical characterization of the composite material.
- Because shell-derived material alone and commercial activated carbon alone were not evaluated independently, the present study cannot determine the individual contribution of either component or any possible synergistic interaction between them.
- The 1:1 shell-derived material/activated-carbon ratio and the approximately 1:1 adsorbent-to-fish ratio investigated in this study should be regarded as experimental conditions rather than optimized formulations or recommended practical application levels. Further dose–response and formulation studies are required to assess efficiency, scalability, and economic feasibility.
- The results provide preliminary support for further investigation of *Pinctada imbricata radiata* shell waste as a feedstock for value-added materials within a circular-economy framework.
- Overall, the present study demonstrates a preliminary sensory odour-control effect of the investigated composite formulation but does not establish a validated food-preservation technology. Further research, including microbiological and physicochemical measurements, instrumental analysis of volatile compounds, and appropriate multifactorial or mixed-effects statistical modelling, is required to confirm the mechanism, reproducibility, and practical significance of the observed sensory effect.

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Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding authors.

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Conflicts of Interest: The authors declare no conflicts of interest

Supplementary Materials

Table S1. High School Students Recorded Responses to Question 1 of the Olfactory Evaluation of SA With and Without Adsorbent Material

Day	Sample	Panelists - High school students															Average	Standard deviation	Standard error
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15			
2	SAT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1,00	0,00	0,00
	SAC	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1,07	0,26	0,07
4	SAT	1	2	1	1	1	1	1	2	1	1	1	1	1	1	1	1,13	0,35	0,09
	SAC	1	2	1	2	1	1	1	1	1	1	1	1	2	1	2	1,27	0,46	0,12
6	SAT	2	1	1	2	1	2	1	1	2	1	1	1	2	1	1	1,33	0,49	0,13
	SAC	2	2	1	1	2	2	1	2	1	2	1	1	1	2	1	1,47	0,52	0,13
8	SAT	2	3	2	3	2	3	3	3	2	3	3	3	2	3	3	2,67	0,49	0,13
	SAC	4	3	4	3	4	3	4	3	4	3	4	4	3	4	3	3,53	0,52	0,13
10	SAT	4	4	4	2	2	4	2	4	2	3	4	3	5	4	5	3,47	1,06	0,27
	SAC	4	3	4	3	4	3	4	4	4	3	4	4	4	4	4	3,73	0,46	0,12
12	SAT	4	4	4	2	2	4	2	4	2	3	4	3	5	4	5	3,47	1,06	0,27
	SAC	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5,00	0,00	0,00

Table S2. High School Students Recorded Responses to Question 1 of the Olfactory Evaluation of CH With and Without Adsorbent Material

Day	Sample	Panelists - High school students															Average	Standard deviation	Standard error
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15			

2	CHT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1,00	0,00	0,00
	CHC	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1,00	0,00	0,00
4	CHT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1,00	0,00	0,00
	CHC	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1,00	0,00	0,00
6	CHT	2	1	1	2	1	1	2	1	1	1	1	1	1	1	1	1,20	0,41	0,11
	CHC	2	1	1	2	1	1	2	1	1	2	1	1	1	1	1	1,27	0,46	0,12
8	CHT	1	1	2	2	2	2	1	2	2	2	1	2	2	1	2	1,67	0,49	0,13
	CHC	2	3	1	2	3	3	2	1	2	2	2	2	3	3	2	2,20	0,68	0,18
10	CHT	1	1	2	2	3	1	1	2	3	2	1	2	3	1	3	1,87	0,83	0,21
	CHC	3	3	1	2	3	3	2	1	2	3	3	2	3	2	2	2,33	0,72	0,19
12	CHT	2	2	2	2	2	2	2	3	2	2	2	2	2	2	2	2,07	0,26	0,07
	CHC	3	3	1	2	3	3	2	1	3	3	3	2	3	3	5	2,67	0,98	0,25

Table S3. High School Students Recorded Responses to Question 2 of the Olfactory Evaluation of SA With and Without Adsorbent Material

Day	Sample	Panelists - High school students															Average	Standard deviation	Standard error
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15			
2	SAT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1,00	0,00	0,00
	SAC	1	1	1	1	1	1	1	1	2	1	1	1	1	1	2	1,13	0,35	0,09
4	SAT	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1,07	0,26	0,07
	SAC	1	1	1	2	1	1	1	1	2	1	1	1	1	1	2	1,20	0,41	0,11
6	SAT	1	1	1	1	1	2	1	1	1	1	1	1	1	2	1	1,13	0,35	0,09
	SAC	2	1	1	1	1	2	1	1	1	2	1	1	1	1	2	1,27	0,46	0,12
8	SAT	1	2	1	4	2	2	4	2	2	1	4	1	5	2	2	2,33	1,29	0,33
	SAC	2	2	1	2	3	2	2	2	3	2	3	3	2	2	5	2,40	0,91	0,24
10	SAT	4	4	3	2	1	4	2	3	2	3	3	2	3	4	4	2,93	0,96	0,25
	SAC	2	2	3	4	4	2	4	3	2	2	4	2	3	4	5	3,07	1,03	0,27
12	SAT	4	4	3	2	1	4	2	3	1	5	4	2	5	4	5	3,27	1,39	0,36
	SAC	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5,00	0,00	0,00

Table S4 High School Students Recorded Responses to Question 2 of the Olfactory Evaluation of CH With and Without Adsorbent Material

Day	Sample	Panelists - High school students															Average	Standard deviation	Standard error
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15			
2	CHT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1,00	0,00	0,00
	CHC	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1,00	0,00	0,00
4	CHT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1,00	0,00	0,00
	CHC	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1,07	0,26	0,07
6	CHT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1,00	0,00	0,00
	CHC	1	1	1	2	1	1	2	1	1	1	1	1	1	1	1	1,13	0,35	0,09
8	CHT	2	2	2	2	2	2	2	2	2	2	1	2	2	2	2	1,93	0,26	0,07
	CHC	2	2	2	2	2	2	2	2	2	2	2	2	2	2	5	2,20	0,77	0,20
10	CHT	1	2	1	2	2	2	2	2	2	1	2	2	5	2	2	2,00	0,93	0,24
	CHC	1	1	1	1	1	1	1	1	5	5	2	3	3	3	2	2,07	1,44	0,37
12	CHT	2	2	2	2	2	2	2	2	2	2	2	2	3	2	2	2,07	0,26	0,07
	CHC	2	2	2	3	2	2	3	2	2	3	2	3	3	3	2	2,40	0,51	0,07

Table S5. High School Students Recorded Responses to Question 3 of the Olfactory Evaluation of SA With and Without Adsorbent Material

Day	Sample	Panelists - High school students															Average	Standard deviation	Standard error
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15			
2	SAT	1	1	1	1	1	2	1	1	1	1	1	1	1	1	2	1,13	0,35	0,09
	SAC	1	1	1	1	1	2	1	1	1	1	1	1	2	1	2	1,20	0,41	0,11
4	SAT	1	1	1	1	1	2	1	1	1	1	1	1	2	1	2	1,20	0,41	0,11
	SAC	1	1	2	1	1	2	1	1	1	1	1	1	2	1	2	1,27	0,46	0,12
6	SAT	1	1	1	1	2	1	1	2	2	1	2	1	1	2	1	1,33	0,49	0,13
	SAC	1	2	1	1	2	1	2	1	1	2	2	1	1	2	1	1,40	0,51	0,13
8	SAT	1	1	1	4	1	1	4	1	1	1	4	1	5	1	1	1,87	1,51	0,39
	SAC	2	2	1	3	3	2	2	2	3	2	2	3	2	2	3	2,27	0,59	0,15

10	SAT	2	2	2	4	2	2	4	2	2	2	3	2	4	2	1	2,40	0,91	0,24
	SAC	2	3	3	1	2	3	1	3	1	1	4	2	4	3	4	2,47	1,13	0,29
12	SAT	1	4	4	3	3	4	3	2	5	5	1	3	2	3	1	2,93	1,33	0,34
	SAC	1	5	1	5	1	5	5	1	5	5	5	5	1	5	5	3,67	1,95	0,50

Table S6. High School Students Recorded Responses to Question 3 of the Olfactory Evaluation of CH With and Without Adsorbent Material

Day	Sample	Panelists - High school students															Average	Standard deviation	Standard error
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15			
2	CHT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1,00	0,00	0,00
	CHC	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1,00	0,00	0,00
4	CHT	1	1	1	1	1	2	1	1	1	1	1	1	1	1	2	1,13	0,35	0,09
	CHC	1	1	1	1	1	2	1	1	1	1	1	1	2	1	2	1,20	0,41	0,11
6	CHT	1	1	1	1	1	2	1	1	2	1	1	1	1	2	1	1,20	0,41	0,11
	CHC	1	1	2	1	1	1	1	1	1	1	1	2	1	2	2	1,27	0,46	0,12
8	CHT	1	2	1	1	1	1	1	1	1	1	1	1	1	1	5	1,33	1,05	0,27
	CHC	2	2	1	2	2	1	2	2	2	2	1	2	2	1	2	1,73	0,46	0,12
10	CHT	1	1	1	1	1	1	1	1	2	2	2	1	3	2	2	1,47	0,64	0,17
	CHC	1	2	1	1	3	2	3	3	3	3	2	3	2	2	5	2,40	1,06	0,27
12	CHT	2	2	3	2	2	1	2	1	2	2	2	2	2	2	2	1,93	0,46	0,12
	CHC	1	3	1	3	1	3	3	1	5	5	3	3	5	3	3	2,87	1,41	0,36

Table S7. High School Students Recorded Responses to Question 4 of the Olfactory Evaluation of SA With and Without Adsorbent Material

Day	Sample	Panelists - High school students															Average	Standard deviation	Standard error
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15			
2	SAT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1,00	0,00	0,00
	SAC	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1,00	0,00	0,00
4	SAT	1	1	1	1	1	1	2	1	1	1	1	1	1	2	1	1,13	0,35	0,09
	SAC	2	1	2	1	2	1	1	1	1	1	1	1	2	1	1	1,27	0,46	0,12

6	SAT	2	1	1	1	1	1	1	1	1	2	1	2	1	1	1	1,20	0,41	0,11
	SAC	2	2	1	1	1	1	2	1	2	1	1	1	1	2	1	1,33	0,49	0,13
8	SAT	3	3	2	2	3	3	3	3	3	3	3	2	3	2	3	2,73	0,46	0,12
	SAC	3	3	2	2	3	2	3	3	3	3	3	3	3	3	3	2,80	0,41	0,11
10	SAT	4	4	2	2	3	4	3	4	3	4	4	3	4	4	5	3,53	0,83	0,21
	SAC	3	3	3	5	5	2	5	3	3	3	5	3	3	5	5	3,73	1,10	0,28
12	SAT	4	4	4	4	4	4	3	4	4	4	3	5	4	4	4	3,93	0,46	0,12
	SAC	5	5	5	5	5	5	5	5	5	5	5	4	4	4	5	4,80	0,41	0,11

Table S8. High School Students Recorded Responses to Question 4 of the Olfactory Evaluation of CH With and Without Adsorbent Material

Day	Sample	Panelists - High school students															Average	Standard deviation	Standard error
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15			
2	CHT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1,07	0,26	0,07
	CHC	2	1	1	1	1	1	1	1	2	1	1	1	1	2	2	1,27	0,46	0,12
4	CHT	2	1	1	1	1	1	1	1	2	1	1	1	1	2	2	1,27	0,46	0,12
	CHC	2	1	1	1	1	1	1	1	2	1	2	1	1	2	2	1,33	0,49	0,13
6	CHT	2	1	1	1	2	1	1	1	2	2	1	1	2	1	2	1,40	0,51	0,13
	CHC	2	1	1	1	2	1	1	1	2	2	1	1	2	2	2	1,47	0,52	0,13
8	CHT	2	2	1	2	2	2	2	2	2	1	2	2	2	1	1	1,73	0,46	0,12
	CHC	2	1	2	1	2	1	1	3	4	2	1	1	1	4	3	1,93	1,10	0,28
10	CHT	1	2	2	1	2	2	2	2	2	2	1	2	3	2	2	1,87	0,52	0,13
	CHC	2	1	3	1	2	3	1	3	2	2	3	3	2	2	2	2,13	0,74	0,19
12	CHT	2	2	1	2	2	2	2	2	2	2	2	2	2	2	3	2,00	0,38	0,10
	CHC	4	1	3	1	5	1	1	3	4	5	1	1	1	4	3	2,53	1,60	0,41

Table S9. High School Students Recorded Responses to Question 5 of the Olfactory Evaluation of SA With and Without Adsorbent Material

Day	Sample	Panelists - High school students															Average	Standard deviation	Standard error
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15			

2	SAT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1,00	0,00	0,00
	SAC	2	1	1	1	2	1	1	1	1	2	1	1	1	1	1	1,20	0,41	0,11
4	SAT	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1,07	0,26	0,07
	SAC	2	2	1	1	2	1	1	1	1	2	1	1	1	1	2	1,33	0,49	0,13
6	SAT	2	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1,13	0,35	0,09
	SAC	2	2	2	2	1	2	1	1	1	1	1	2	1	2	1	1,47	0,52	0,13
8	SAT	2	1	2	2	1	2	2	2	2	2	1	2	2	1	2	1,73	0,46	0,12
	SAC	1	1	4	4	4	1	4	4	4	1	4	3	5	1	1	2,80	1,57	0,41
10	SAT	2	3	2	3	1	3	3	2	1	2	3	3	5	2	3	2,53	0,99	0,26
	SAC	4	4	4	4	4	4	3	4	4	4	4	3	5	4	4	3,93	0,46	0,12
12	SAT	3	3	3	3	3	3	3	3	5	5	2	5	5	5	2	3,53	1,13	0,29
	SAC	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5,00	0,00	0,00

Table S10. High School Students Recorded Responses to Question 5 of the Olfactory Evaluation of CH With and Without Adsorbent Material

Day	Sample	Panelists - High school students															Average	Standard deviation	Standard error
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15			
2	CHT	2	1	1	1	1	1	2	1	2	1	2	1	1	1	1	1,27	0,46	0,12
	CHC	2	2	1	1	1	1	1	1	2	1	2	1	1	2	1	1,33	0,49	0,13
4	CHT	2	1	1	1	1	1	2	1	2	1	2	1	2	1	2	1,40	0,51	0,13
	CHC	2	2	1	1	1	1	2	1	2	1	2	1	2	2	2	1,53	0,52	0,13
6	CHT	2	1	2	1	1	2	1	1	2	2	2	2	2	2	2	1,67	0,49	0,13
	CHC	1	1	2	2	1	1	1	2	1	2	2	2	5	2	2	1,80	1,01	0,26
8	CHT	2	2	2	2	2	1	2	2	2	2	2	2	3	2	2	2,00	0,38	0,10
	CHC	5	2	2	3	3	2	3	2	3	3	2	3	2	3	3	2,73	0,80	0,21
10	CHT	2	2	2	3	2	2	3	2	3	2	2	2	3	2	2	2,27	0,46	0,12
	CHC	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3,07	0,26	0,07
12	CHT	1	1	2	2	3	2	2	4	4	2	4	3	3	2	4	2,60	1,06	0,27
	CHC	4	3	3	4	4	3	4	3	4	4	2	4	3	4	4	3,53	0,64	0,17

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