Best recommended method for washing to disinfect and deodorise waste turkey feathers intended for insulation purposes

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ABSTRACT – REZUMAT

Best recommended method for washing to disinfect and deodorise waste turkey feathers intended for insulation purposes

Waste turkey feathers (TF) must be washed to be used in the production of composite or nonwoven surfaces. Despite cleaning, these fibres can develop strong odours, especially as temperature increases. The gas chromatography-mass spectrometry (GC-MS) method was used to determine the oils and fatty acids that cause odour in clean or dirty TF structure and to see their changes depending on temperature. Fourier transform infrared spectroscopy (FTIR) and scanning electron microscopy (SEM) images were used to determine whether there was any change in the chemical structure of the feathers after washing. The washing program results were compared, and the W6S program was identified as the most effective method for eliminating volatile substances that may cause odour. According to GC-MS results, the total area of the peaks covered by fatty acids and other substances in the chromatogram decreased by 593 times at 24°C and by 1250 times at 85°C compared to the W1 washing program. This situation provided saponification under the effect of sodium hypochlorite, which is a very strong base. Then, washing with nonionic soap, rinsing with sodium hydroxide and centrifuging were carried out to obtain odourless TF.

Keywords: *turkey feather, disinfection of turkey feathers, bad odours, fibre washing method, gas chromatography-mass spectrometry*

Cea mai recomandată metodă de spălare pentru dezinfectarea și dezodorizarea penelor de curcan uzate, destinate izolării termice

Penele de curcan reziduale (TF) trebuie spălate pentru a putea fi utilizate în producția de suprafețe compozite sau nețesute. În ciuda procesului de curățare, aceste fibre pot emana mirosuri foarte neplăcute, în special odată cu creșterea temperaturii. Metoda cromatografiei de gaze-spectrometriei de masă (GC-MS) a fost utilizată pentru a identifica uleiurile și acizii grași care provoacă mirosul în structura TF curate sau murdare și pentru a observa modificările acestora în funcție de temperatură. Imaginile au fost obținute prin spectroscopie în infraroșu cu transformată Fourier (FTIR) și cu microscopul electronic de baleiaj (SEM) pentru a determina dacă a existat vreo modificare a structurii chimice a penelor după spălare. Rezultatele programelor de spălare au fost comparate și s-a stabilit că cea mai eficientă metodă de curățare pentru eliminarea substanțelor volatile care pot provoca mirosuri neplăcute este programul W6S. Conform rezultatelor GC-MS, aria totală a vârfurilor corespunzătoare acizilor grași și altor substanțe din cromatogramă a scăzut de 593 de ori la 24°C și de 1250 de ori la 85°C, comparativ cu programul de spălare W1. Această situație a permis saponificarea sub efectul hipocloritului de sodiu, care este o bază foarte puternică. Apoi, s-a efectuat spălarea cu săpun neionic, urmată de clătirea cu hidroxid de sodiu și centrifugare, pentru a se obține TF inodore.

Cuvinte-cheie*: pene de curcan, dezinfectarea penelor de curcan, mirosuri neplăcute, metoda de spălare a fibrelor, cromatografie de gaze-spectrometrie de masă*

INTRODUCTION

As a result of turkey meat production, a large amount of TF is released. The statistics show that more than 600 million turkeys are slaughtered every year for meat [1]. It is stated that the total meat production in the 15 countries that produced the most turkey meat worldwide in 2021 was 6.1 million tons [2]. The weight of a TF varies depending on factors such as breed and feeding conditions. Research shows that mature feather weights for different turkey species are around 440 g for female Ross turkeys and 620 g for males [3, 4]. When the number of turkeys slaughtered annually in the world and the average amount of feathers on a turkey are taken into account, it is seen that approximately 0.5 million tons of TF can be released annually. It is predicted that this waste material will increase every year due to increasing turkey meat production.

When the literature is examined, it is seen that a very small portion of these waste feathers are ground and used as feed after boiling at temperatures of 140°C or higher. It is understood that the majority of feathers other than these are disposed of by burning or burying them in the ground. These waste feathers pollute soil, surface water, and groundwater and produce greenhouse gases [5, 6]. Turkey and poultry feathers contain large amounts of nitrogen, which causes high amounts of nitrogen oxides (NOx) to

form during the burning process. This transformation can also lead to the formation of hydrogen cyanide (HCN) [7]. Researchers say burning poultry waste can produce more toxic air emissions than coal-fired power plants [8–10].

There are searches for the use of these wastes in industrial areas or buildings. Turkey and poultry feathers are used in ready-made clothing as filling material, panels for heat and sound insulation, paper production, and in the production of composite materials for insulation purposes by covering them with decorative fabrics. To obtain and use fibre from TF, it must be cleaned of dirt, blood, bacteria, dust, and oil, and it must be ensured that it does not smell or deteriorate over time. Turkeys, like other poultry, have oil that they produce from their bodies. This oil often sticks to the feathers and does not come off unless you clean it well. When feathers are processed at different temperatures, these oils can cause unpleasant odours [11]. Many substances in the feather structure can cause odour or cause the feather to deteriorate and rot. According to Costa and his friends, feathers have approximately 99% volatile solids [12]. About 92% of these are protein and 2.79% are fat [13]. Turkeys regularly oil their feathers throughout their lives. A male Ross turkey accumulates 0.114 grams of oil in his feathers per day [3]. This situation causes heavy oil to accumulate in the feathers over time. When feathers are plucked, there is a breakdown of the oils in the feathers. It is important to remove this broken oil from the feathers. Therefore, the method used to eliminate oil during washing to be performed is very important.

There are no significant studies on the detailed washing and disinfection of TF in the literature. However, there are studies using different methods for washing wool, chicken, and some bird feathers. One group of researchers washed bird feathers in ethanol. The purpose of the ethanol washing process is to clean the feathers and remove any lingering odour [14–17]. Some researchers washed the feathers with detergent and dried them [18]. There are also studies on the effects of washing with different surfactants on the structure of chicken feathers [19]. In another study, fresh feathers taken from chicken bodies were washed in water, aired for a period of time, and then dried in an oven. To eliminate any residual oils, the feathers were treated with petroleum ether utilising a Soxhlet apparatus [20].

There are studies showing that using equipment such as an ultrasound bath and centrifuge positively impacts washing quality and significantly increases cleaning efficiency by removing unwanted substances, bacteria, and moisture from the fibres. Researchers are using ultrasonic cleaning because of its cleansing and antibacterial properties [21–23]. In ultrasonic washing, mechanical actions that help clean fabrics are provided by sound waves [24]. In his research, Ma used ultrasonic energy to clean silk fabrics, aiming to achieve a better appearance after washing. He found that it provided better results than machine washing in removing common stains and maintaining the fabric's appearance and dimensions [25].

Another effective method for cleaning, partial drying, and deodorisation after washing is centrifugation. This process removes dirt, bacteria, and moisture from the fibres, which increases its cleaning efficiency. There are many patented centrifuge cleaning machines with different operating principles available. These machines feature a rotating carousel and a servo-controlled shower nozzle to efficiently wash products. High-speed rotating systems separate the fibres from the liquids, removing surface dirt. During the cleaning process, they utilise a belt, a cleaning device, and an induced draft system to minimise secondary contamination by absorbing water vapour [26–29]. For example, it has been stated that the separation of wool wax becomes easier when fibres that contain a lot of oil in their structure, such as wool, are centrifuged after washing [30, 31]. Centrifuging after yarn dyeing in the package effectively removes 88.2% of solid impurities, resulting in cleaner, smoother fibres. Centrifuging improves friction and electrical properties while reducing spinning dust [32].

Another method used to disinfect bird feathers is the use of ultraviolet (UV) light. Xiaolin and his colleagues have successfully and effectively eliminated bacteria in feathers with the UV device they developed for cleaning and disinfecting bird feathers. The use of UV light is complemented by mechanical systems that ensure the feathers are fully exposed to the disinfecting agents, increasing their overall effectiveness [33, 34]. Yungang has received a patent for cleaning protein fibres with a UV method, removing dust and bacteria. In addition, cleaning efficiency has been increased by designing devices with improved electrostatic, mechanical, and dust collector components and friction mechanisms to increase cleaning efficiency [35].

Another method used in feather processing is ozone disinfection. A new device has been developed to achieve comprehensive sterilisation and odour removal by adding ozone to the ultraviolet disinfection method [34]. Some researchers have developed specialised equipment for cleaning and disinfecting feathers. These devices have been reported to shorten cleaning and disinfection processes and decrease worker workload, resulting in more efficient results [36]. There are studies that subject feathers to an ozonisation process after a conventional wash with surfactants and disinfectants. Ozone's antibacterial properties and odour-eliminating properties were utilised to achieve this cleaning [37, 38].

Fayez and Halıq, in their studies on the disinfection of some bacteria present in poultry hatcheries, stated that disinfectants such as Aquavinol® at a concentration of 5% showed superior effectiveness against pathogens such as E. coli and Salmonella [39]. Paşayev and colleagues found that the most effective cleaning method in terms of removing volatile substances that can cause foul odour from chicken feathers was a short pre-wash with sodium hypochlorite and a finishing treatment with sodium hydroxide

solution, followed by a main wash with a nonionic detergent [40]. It has been stated that ideal cleaning and disinfection are achieved in the washing with sodium hypochlorite in a household washing machine when cleaning the feathers of poultry [41].
When these results from the literature and the data obtained from my applications are examined, it becomes clear that as the time the feathers remain dirty without being washed increases, disinfection becomes more difficult, and removing the odour from the fibres becomes almost impossible. A review of the literature reveals no studies on the disinfection of waste TF. The first step in using waste material for the production of high-value-added products is disinfection and making it smell clean. In this study, different washing methods were used, and after testing the results, the best method was determined and recommended for researchers and manufacturers interested in working in this field.

MATERIAL AND METHOD

Material

The TF used in this study was supplied dirty from a local business and received approximately two days later. To prevent odour and damage to the feathers, a quick, simple wash and rinse with water was performed, then they were dried and prepared for washing. Eleven different recipes, and therefore different chemicals, were used in the washing processes. Chemicals such as soda (Na_2CO_3), nonionic detergent alkyl phenol ethylene oxide (phenyl ethyl alcohol), neutral granular soap, carbon tetrachloride (CCl_4), sodium hypochlorite (NaClO), and sodium hydroxide (NaOH) were used. Equipment such as beakers, heaters, ultrasound devices, and centrifuges was used according to the washing method and program.

Working method

Approach

The fibres need to be disinfected to produce a high-value-added product from TFs and to ensure their long-term use. The feathers must be free from oil, dirt, dust and blood and bodily fluids which accumulate on them during wet removal. The production of TF requires the use of chemicals, hot water, and sometimes a hot press. The oils in the TF can cause odour due to these heat treatments. Various chemicals were used to remove odour because acidic or alkaline washing conditions are required to remove odour. The quantity of chemicals used, the water temperature in the recipes, and the processing times were analysed based on the results of preliminary studies and then applied according to the best wash recipe. The GC-MS device was used to determine the elements that remained in the feather structure after the washings and could cause odour. The feathers subjected to 11 different washing procedures were measured at 24°C and 85°C. The odour produced by the feathers varies depending on the temperature. By comparing the resulting chromatograms, conclusions were drawn about the effects of different temperature regimes on the odour of the feather material, depending on the washing method. Images were taken using a JEOL JSM-6510 scanning electron microscope (SEM) to examine the surface and internal structural morphology of the TFs. Fourier transform infrared spectroscopy (FTIR) analyses were also conducted to assess changes in the chemical structure of the feathers after washing.

SEM image of turkey feathers

One sample was taken from each of 11 washing processes performed using different recipes to examine the structural properties of the fibres. To this end, the fibres were cross-sectioned using a scalpel from the hard part of the feather called the rachis. After the fibres were coated with Pd/Au, they were imaged with an SEM to examine their internal structure.

Preparation of washing methods and washing programs

Detailed information about the washing programs (coded W2, W3, W4, W5, and W6) is provided in table 1, along with washing charts that list the recipes, chemical cleaners, temperatures, and durations for which they are used. The W1 wash is a prewash performed to remove natural and artificial impurities, such as dirt, sweat salts, dyes, etc., from the TF. No washing agents were used in this wash, and the dirty feathers were washed at 30°C for 5 minutes. The goal is to begin the main wash with relatively cleaner fibres. The feather quantity used in these studies is 50 grams, and the liquor ratio is 1:20.
In this study, the TFs coming out of each of the available washing programs were subjected to the spinning and drying process in the centrifuge machine for 15 minutes. The purpose here is to demonstrate the washing effect and odour removal effects of centrifugation. By removing the small amounts of oil, dirt, liquids, and chemicals trapped between the fibres during this process, the result is cleaner, odourless, and drier fibre. The washing processes run through the centrifuge are coded as W2S, W3S, W4S, W5S, and W6S. Figure 1 provides a graphical summary of these washing processes.

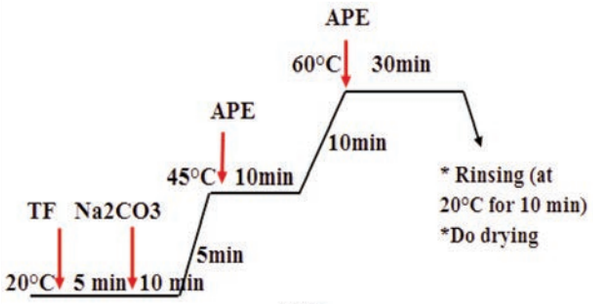
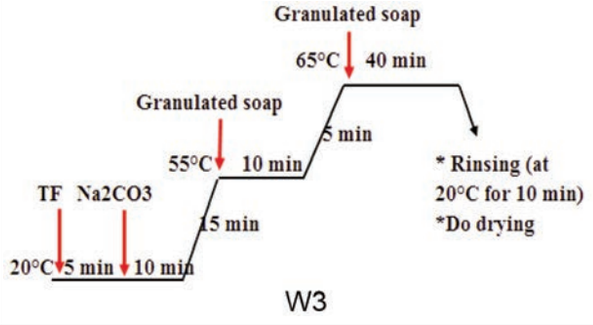
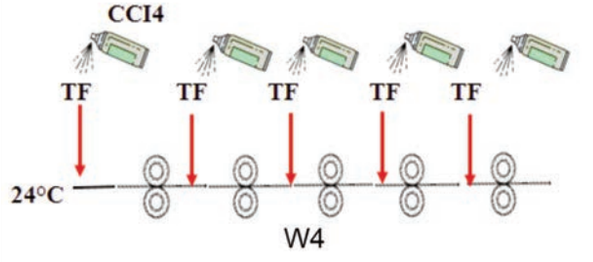
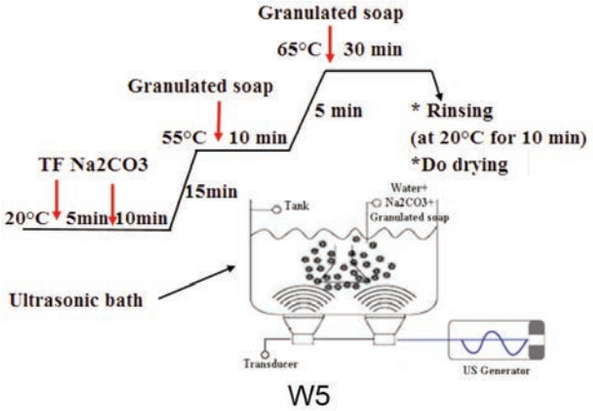
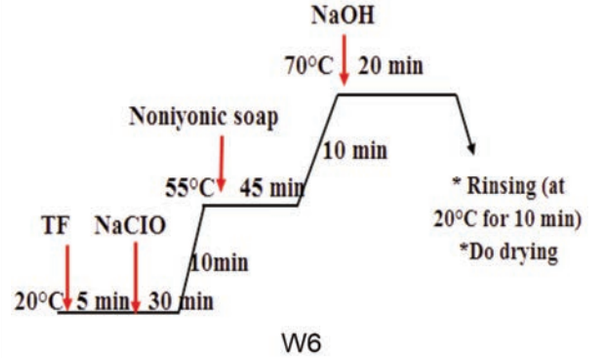
FTIR analysis of feathers washed in different ways

FTIR spectroscopy was used to determine whether there were any changes in the chemical structure of the feathers after washing. For this purpose, measurements were taken from samples of dirty and washed feathers.

Gas chromatography-mass spectrometry (GC-MS)

Steam distillation was used to obtain extracts from feather samples that had been cleaned. An Agilent 7890A GC/5970C model MS detector and an Optima delta-60, 0.25 micrometre (60 m × 0.25 mm ID) column were employed in a GC-MS instrument that used a flame ionisation detector (FID) and MS detectors concurrently for this purpose. The headspace method was used to establish the chromatographic conditions. One gram of TF was weighed on a precision balance and put in a GC vial for this purpose.

WASHİNG PROGRAMMES, CHEMİCALS USED AND PROCESSİNG TİMES

Washing programme chart	Chart explanation
 W2	At a temperature of 20°C, 50 g of TF subjected to the W1 process is soaked in 1 litre of water for 5 minutes. Then, Na_2CO_3 (sodium carbonate) is added to the mixture, and the process is continued for another 10 minutes. The solution temperature is raised to 45°C within 5 minutes. At this stage, 2.5 g of hydrophilic non-ionic detergent Alkyl Phenol Ethylene (APE) is added, and the mixture is processed for 10 minutes. The temperature is then raised to 60°C within 10 minutes, and at this stage, an additional 2.5 g of APE is added, followed by a 30-minute wash. The sample is then removed, rinsed, and dried at 20°C for 10 minutes.
 W3	50 g of TF, which has undergone the W1 wash process, is soaked in 1 litre of water at 20°C for 5 minutes. It is then treated with Na_2CO_3 for 10 minutes. The solution temperature is raised to 55°C within 15 minutes. At this stage, 4 g of granular soap is added, and the process is continued for 10 minutes. The temperature is then raised to 65°C within 5 minutes, and another 4 g of granular soap is added at this stage, and the wash is continued for 40 minutes. The sample is then removed and rinsed at 20°C for 10 minutes. The process is completed by drying.
 W4	In the W4 program, 200 mL of carbon tetrachloride (CCl_4) solvent was used instead of water. CCl□ is a colourless, non-flammable, heavier-than-water liquid with a chloroform-like odour. In this wash, the feathers were laid out on a fibre mat and sprayed with solvent. Then, they were passed between two rollers for squeezing. The process was completed by spraying the solvent five times and passing through the squeezing rollers.
 W5	The W5 program is the same as the W3 washing program, except that the washing process is carried out in an ultrasonic bath. 50 g of TF, previously subjected to the W1 process, is soaked in 1 litre of water at 20°C for 5 minutes. It is then processed in Na_2CO_3 for 10 minutes. The solution temperature is raised to 55°C within 15 minutes. At this stage, 4 g of granular soap is added, and the process continues for 10 minutes. The temperature is raised to 65°C within 5 minutes, and another 4 g of granular soap is added. After washing for 40 minutes, the sample is removed, rinsed at 20°C for 10 minutes, and dried.
 W6	TF was added to 1 litre of water and soaked for 5 minutes, followed by 50 mL of sodium hypochlorite (NaClO) and pre-washed for 30 minutes. Then, the main washing process was carried out using non-ionic soap. Here, 8 mL of soap washing agent was added to 1 litre of water to prepare the solution, and the pre-washed feathers were washed in this solution at 55°C for 45 minutes while being stirred. After this stage, the feathers were bleached and rinsed. The temperature was raised to 70°C within 10 minutes. 5% of the weight of the washed feathers was added to 1 litre of water as NaOH, and bleaching was carried out at 70°C for 20 minutes. Finally, rinsing and drying were carried out at 20°C for 10 minutes to complete the process.

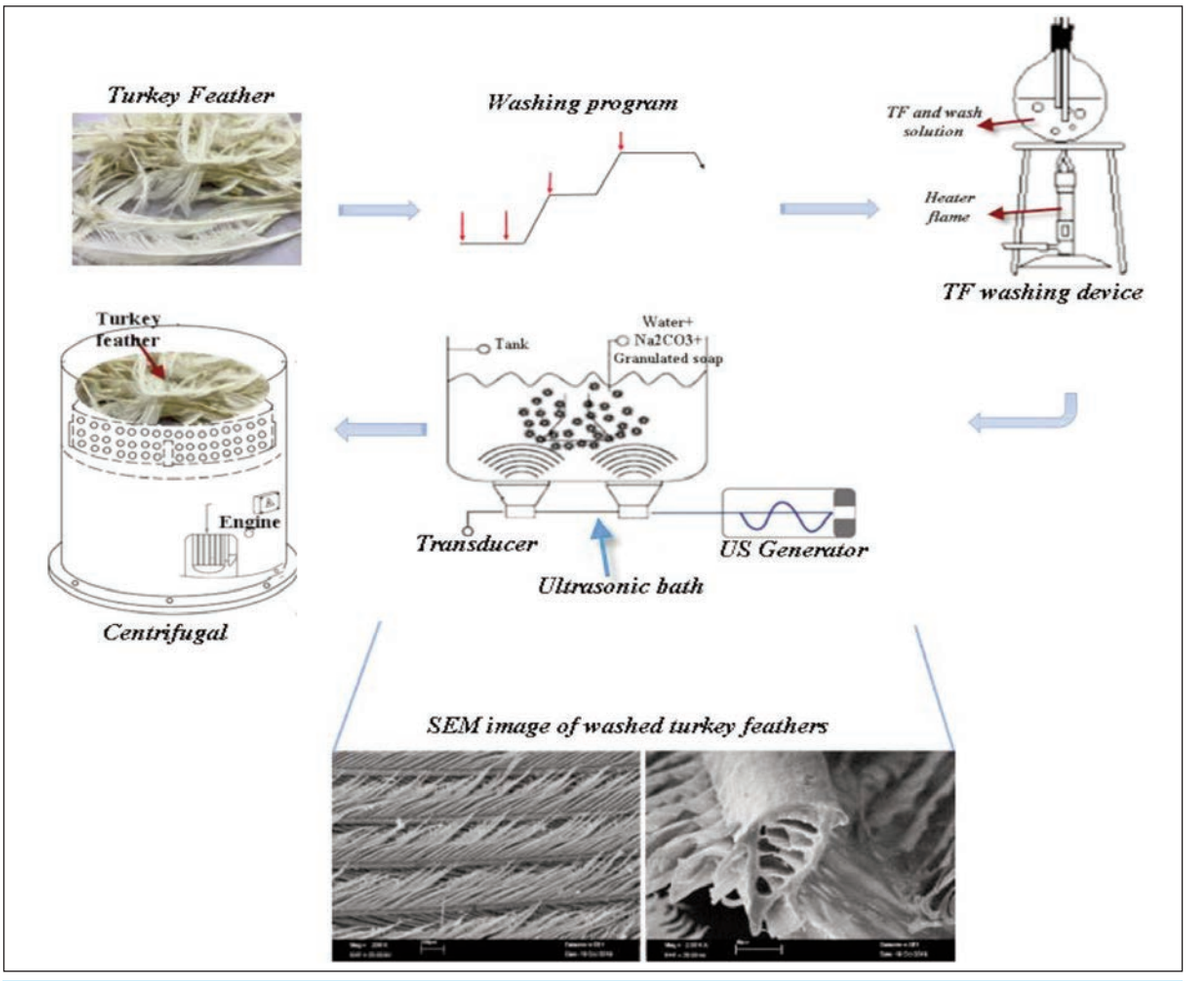


Fig. 1. Graphical summary of the TF washing process

The instrument was filled with the tightly sealed vial. The injector was maintained at 100°C for 30 minutes while the vial was incubated at that temperature. In order to inject 2500 microliters of the final gas into the column, the injector draws gas from the vial three times and then releases it back into the vial.

Conditions for GC-MS: The temperature of the column was maintained at 40°C for 3 minutes, then increased to 190°C at 5°C/min, waited for 3 minutes, then increased to 260°C at 5°C/min, and finally waited for 13 minutes, for a total of 63 minutes. To improve the quality of the separation, a ramped temperature program was chosen. The HS and GC portions of this analysis took 30 and 63 minutes, respectively, for a total analysis time of 93 minutes. The constant gas flow was set at 1 millilitre per minute, and helium was chosen as the carrier gas. The H_2 flow was automatically set to 35 ml/min, the dry air flow to 350 ml/min, and the N_2 to 20–227 ml/min by the instrument software. The Splittles mode was chosen. 290°C was chosen as the ion source, injection temperature, and interface temperature. The m/z (mass/charge) values of the peaks that were obtained and their matches against the Wiley and NIST libraries were used to identify the compound.

RESULT AND DISCUSSION

Morphological properties

After washing, the internal structure of the rachis section of the TF was examined, and its post-washing appearance was examined (figure 2). Accordingly, it was observed that there was no deterioration or deformation in the porous internal structure of the feather.

FTIR results of turkey feathers from different washes

To determine whether the chemical structure of TF was affected by washing and the chemicals used in washing, FTIR analysis was performed on samples taken from dirty and washed feathers. Keratin, which constitutes the majority of cuticle appendages such as hair, nails, animal horns, claws, bird beaks, and bird feathers, is a very common biological material. Insoluble keratin materials, typically composed of proteins with high sulfur content and capable of filament formation, originate from keratin-filled cells and are classified as dead tissue. These biological materials can offer researchers valuable solutions for the production of new structural and functional materials. FTIR analysis of TF samples washed with different washing programs was performed before and after

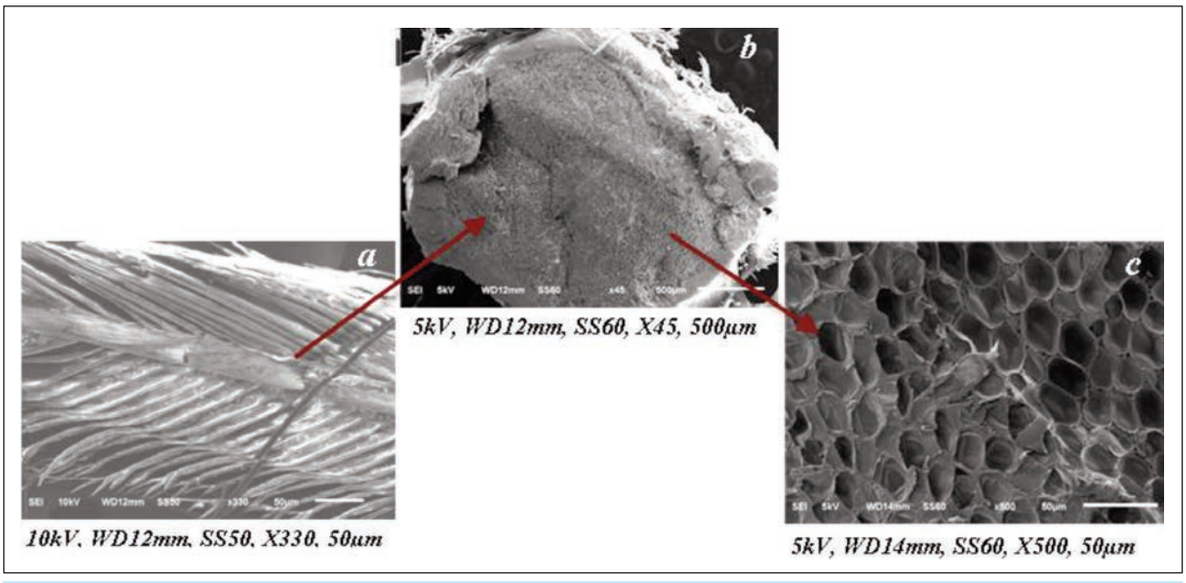


Fig. 2. SEM images of turkey feathers after washing:
a – feather of turkey feather; *b* – rachis section; *c* – hollow internal structure of the feather

washing and cleaning, and TF was analysed in detail. The FTIR spectra of TF in its dirty state (W1) and its washed and disinfected states (W2, W6S, W5) are shown in figure 3. Upon examining the FTIR spectrum obtained from the washed TF samples, the presence of interaction peaks at 3447 (sh broad peak) cm^{-1} from N-H and S-H stretching and possible intramolecular hydrogen bonds formed by –NH bonds is notable. The presence of a characteristic (C=O) peak at around 1705 cm^{-1} (vs very strong), which is found in the main skeleton of the keratin protein, in the FTIR spectrum of the obtained material is an important parameter confirming the keratin structure. The presence of (C1-N), (C3-N), (C1-C1), and ip (C=O) at 1286 cm^{-1}, which are stress peaks originating from C1-N, C3-N, and C1-C1 bonds and planar deformation peaks of the C=O group, also indicates the presence of keratin structure. The peak values of 1535 cm^{-1} and 1521 cm^{-1}, 1635 cm^{-1}, and 1614 cm^{-1} confirm the presence of keratin extract in the obtained material compared with the literature data [42, 43]. The keratin content in the structure was not adversely affected by the washing and disinfection processes, and the resonance peak in the spectrum showed a high degree of similarity to the washed stem sample.

Gas chromatography-mass spectrometry (GC-MS) results

Samples taken from feathers washed and dried using different methods were analysed using a GC-MS device at temperatures of 24°C and 85°C. The peak areas of volatile compounds exceeding 1% in the chromatograms were taken into consideration.

During the GC-MS analysis performed on the extracts obtained at 24°C and 85°C from feathers that underwent only a simple rinsing process with clean water, the retention times (RT), peak areas (PA), and concentrations (% peak area or % PA) of

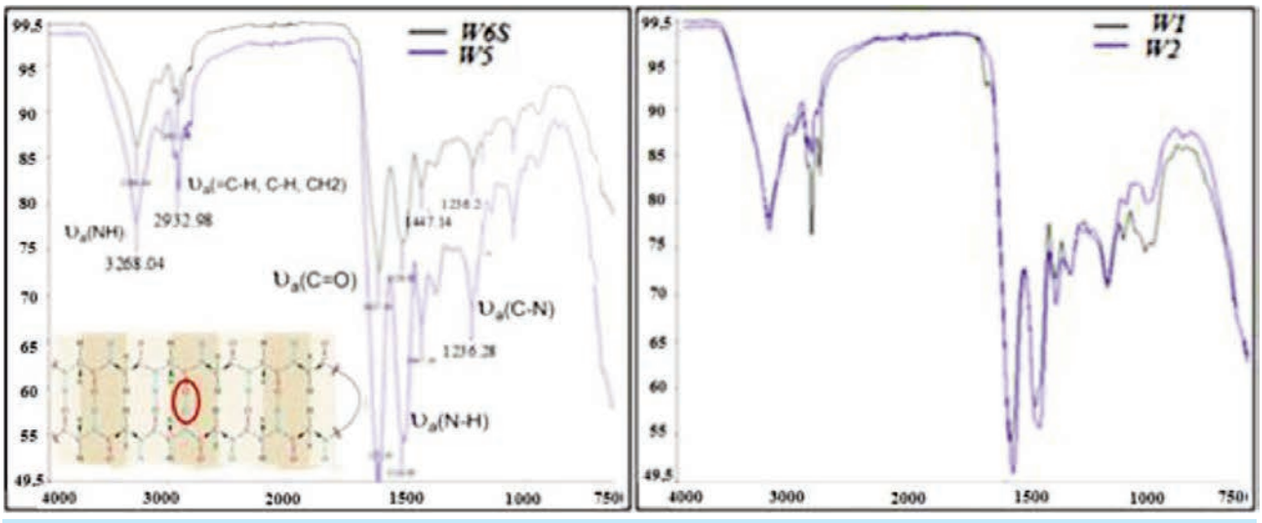


Fig. 3. FTIR spectra of TFs washed according to different washing methods

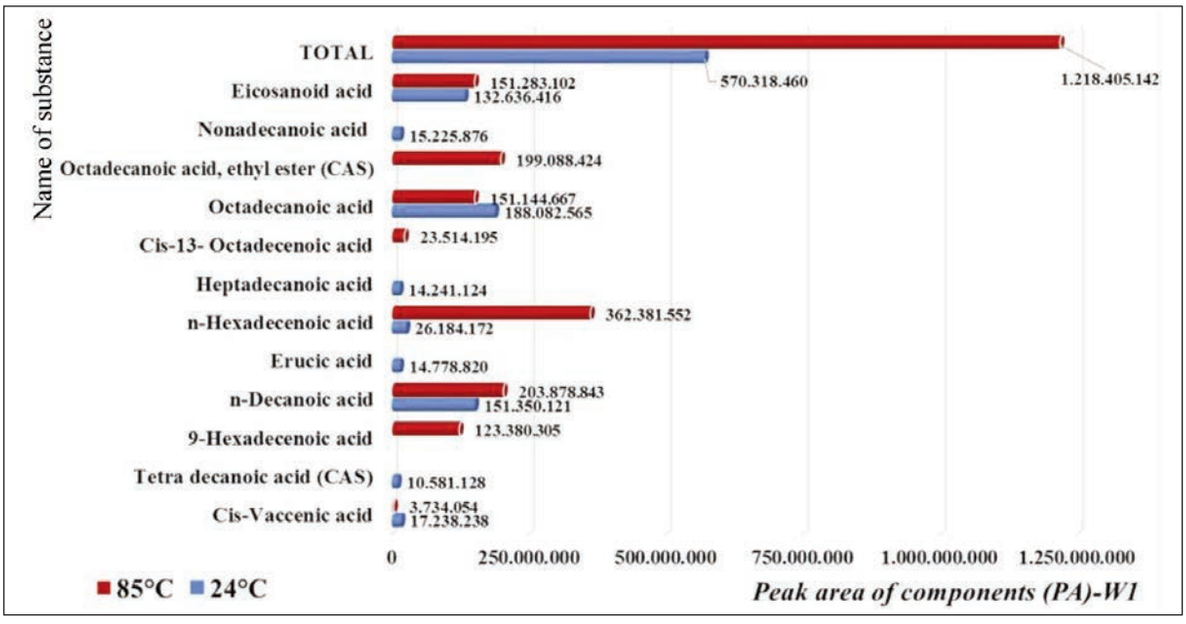


Fig. 4. GC-MS results of W1-coded TF rinsed in pure water

the active components recorded were calculated. The PA, which is the most important data guiding analyses, was considered and reflected in the graphs. The GC-MS results prepared using the PA data of sample W1 at 24°C and 85°C are shown in figure 4.

The presence of volatile substances in the structure of W1-coded turkey feathers rinsed in pure water at different temperatures, and fatty acids released mainly due to hydrolytic changes in the fats in the structure of the feathers, can be observed. When the data in figure 4 is examined, the PA value of the fatty acids in the structure of the W1-coded sample has increased by approximately 2.5 times as the temperature increases. This increase indicates that the odour of the material increases with temperature.

Figure 5 shows the GC-MS analysis results of extracts obtained from feathers washed under washing conditions coded W2 and kept at temperatures of 24°C and 85°C.

When the results in figure 5 are examined, it can be seen that a certain portion of foreign substances and fatty acids in the feathers decreased under the effect of nonionic detergent and sodium carbonate (Na_2CO_3). The overall area of the peaks in the chromatogram covered by fatty acids and other compounds has dropped by 86% at room temperature when comparing the PA data in figure 5 with the data in figure 4. This is a result of the removal of fatty acids due to the effect of the detergent and sodium carbonate used. It is clearly observed that a portion of the fatty acids changes depending on temperature

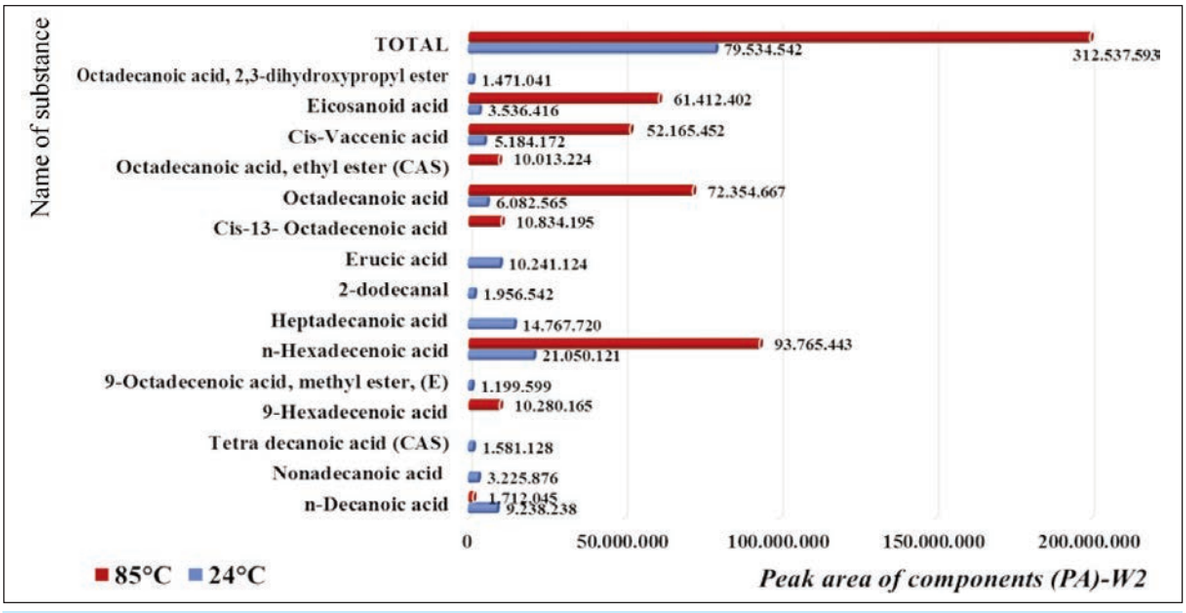


Fig. 5. GC-MS results of TF washed according to prescription code W2

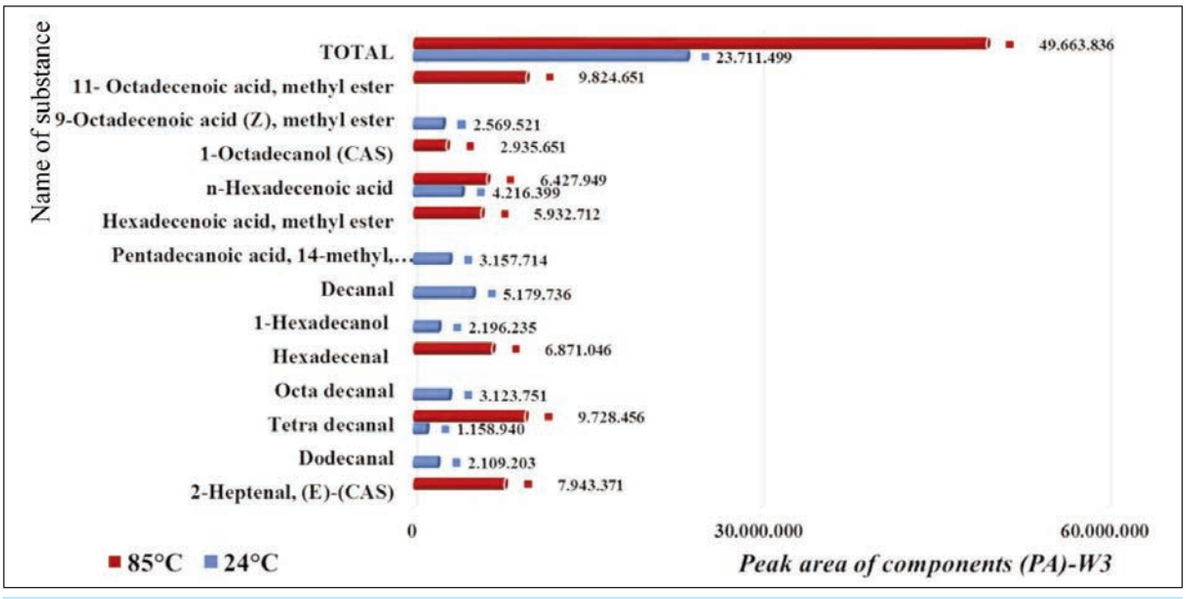


Fig. 6. GC-MS results of TF washed according to W3-coded prescription

variations. Figure 6 shows the GC-MS analysis results of extracts obtained from feathers washed under washing conditions coded W3 and kept at temperatures of 24°C and 85°C.

Looking at the results in figure 6, it can be seen that a significant portion of foreign substances and fatty acids in feathers are reduced by the effect of granular soap and sodium carbonate (Na_2CO_3). When comparing the PA data in figure 6 with the data in figure 4, it is observed that the total area of the peaks covered by fatty acids and other substances in the chromatogram has decreased by 96% at normal temperature. Where the type of fatty acids changes due to the effect of temperature, the detergents used, and the washing method has been identified. However, it was observed that the difference in odour between normal and high temperatures is still very high. The GC-MS analysis results of extracts obtained from feathers washed under washing conditions coded W4 and kept at temperatures of 24°C and 85°C are shown in figure 7.

Examining the results of the W4 washing program, which substitutes a carbon tetrachloride (CCl_4) solvent for water (figure 7), revealed that while the washing result was less successful than W3, it greatly reduced the amount of odour when compared to W1. Overall, though, it appears that the chromatogram's volatile chemical content did not decrease to the intended degree. The fatty acids creating the odour did not reduce to the appropriate level, as seen by the increase in PA brought on by the temperature increase. The GC-MS analysis results of extracts

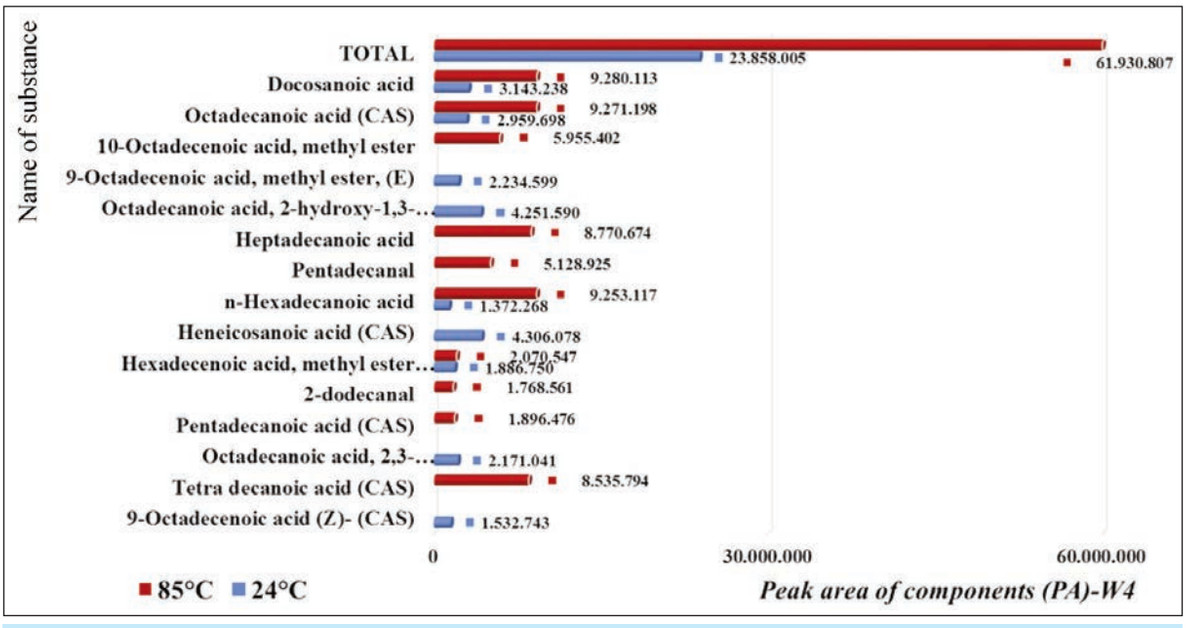


Fig. 7. GC-MS results of TF washed according to prescription code W4

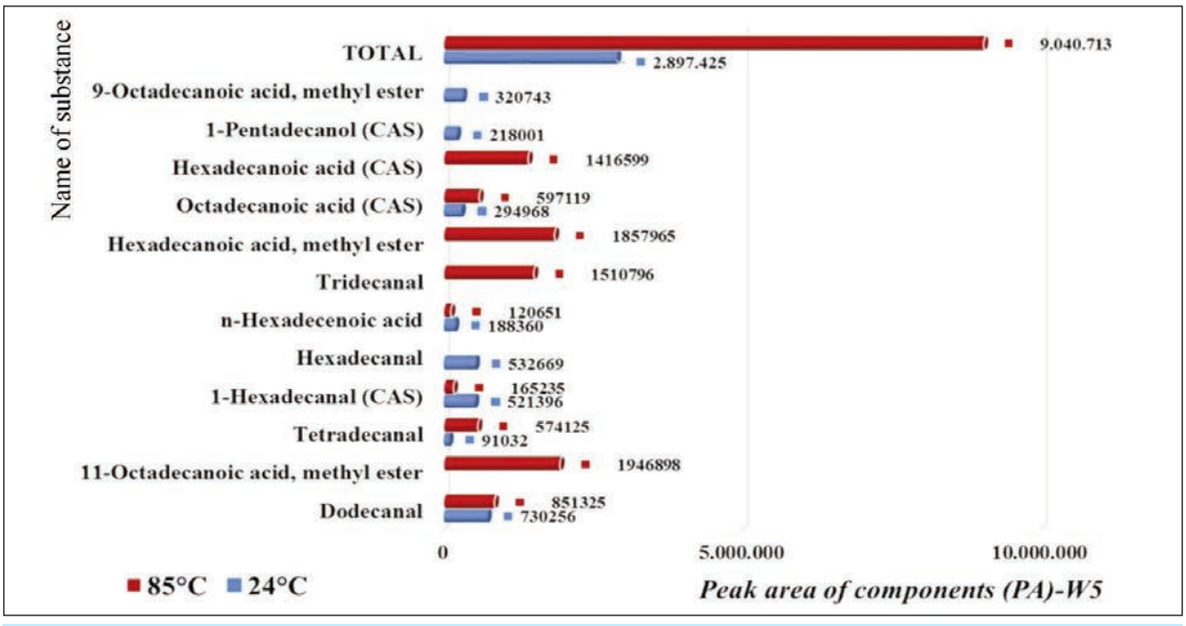


Fig. 8. GC-MS results of TF washed according to prescription code W5

obtained from feathers washed under W5 washing conditions and kept at temperatures of 24°C and 85°C are shown in figure 8.

The main distinction between the W5 and W3 washing programs is that the former uses an ultrasonic bath for the washing procedure. In comparison to the W3 washing process, the chromatograms of the extracts produced at 24°C and 85°C from the samples taken after the W5 washing process demonstrate a considerable decrease in the overall peak areas of the volatiles. This suggests that ultrasonic washing improves the feathers' cleaning capabilities. It is evident from looking at figures 6 and 8 that ultrasonic washing significantly lowers the overall PA. It hasn't yet produced the intended cleaning result, though. Figure 9 displays the GC-MS analysis findings of extracts taken from feathers that were cleaned using washing conditions coded W6 and stored at 24°C and 85°C.

When examining the GC-MS results of extracts obtained from washed feathers at temperatures of 24°C and 85°C, it is evident that the odour remaining in the feathers is primarily caused by fatty acids formed as a result of the hydrolysis of fats and fat residues. For this reason, in the W6 washing method, after the main washing process was carried out with sodium hypochlorite (NaClO) and non-ionic soap, the feathers were subjected to bleaching and rinsing with NaOH to neutralise the fatty acids and residues (table 1 with the detailed recipe).

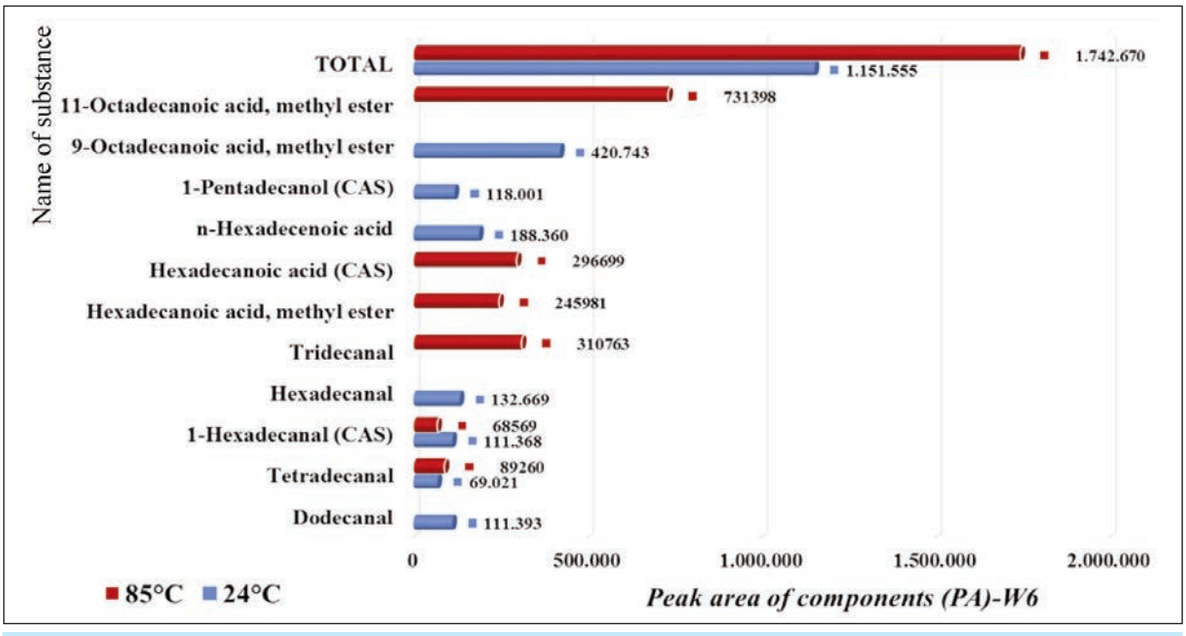


Fig. 9. GC-MS results of TF washed according to prescription code W6

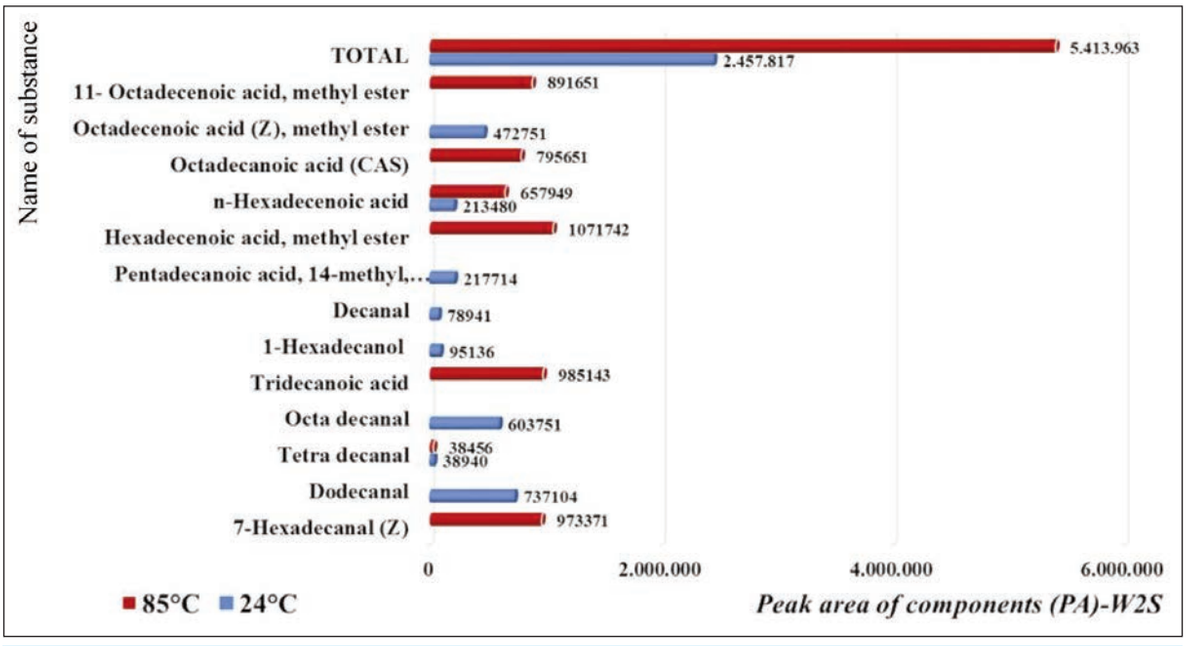


Fig. 10. GC-MS results of TFs washed according to the W2S-coded prescription

When the chromatograms of the samples obtained at low and high temperatures in figure 9 are compared with the chromatograms of the feathers in other washes, it is seen that the total peak areas of the volatile substances formed are minimised.

According to the data in figure 9, it is observed that the total peak area of the volatile compounds released with increasing temperature approaches the total peak area of the volatile compounds released at normal temperature. This suggests that TF's smell won't get stronger as the temperature rises. It has been determined that it is among the best outcomes. Figure 10 shows the GC-MS analysis results of extracts obtained from feathers washed under washing conditions coded W7 and kept at temperatures of 24°C and 85°C. The W2S program is a wash, as determined by processing the feathers washed after the W2 program in a centrifuge machine. To analyse the results of this program, it is possible to compare them with the W2 wash results in figure 5.

The W2S washing programme using a centrifuge machine has been shown to significantly reduce foreign matter and fatty acids in feathers. When compared with the PA data in figure 5, it is observed that the total area of the peaks covered by fatty acids and other substances in the chromatogram decreased by approximately 32 times at 24°C and approximately 58 times at 85°C. This has been evaluated as a result of the centrifuge process used. This result, consistent with the literature, has been confirmed once again by our studies. Another finding is that the types of volatile fatty acids change significantly depending on changes in washing methods. Figure 11 shows the GC-MS analysis results of extracts obtained from feathers washed under W3S washing conditions and kept at temperatures of 24°C and 85°C. The W3S program is a wash, as determined by processing the feathers washed after the W3 program in a centrifuge machine. It is possible to compare the results of this program with the W3 wash results in figure 6.

After W3 washing, it is observed that foreign substances and fatty acids in the feathers are significantly reduced by processing in a centrifuge machine. When compared with the PA data in figure 6, it is observed that the total area of the peaks covered by fatty acids and other substances in the chromatogram decreases by approximately 18 times at 24°C and approximately 15 times at 85°C. This is considered to be a result of the centrifugation process used. Figure 12 shows the GC-MS analysis results of extracts obtained from feathers washed under W4S washing conditions and kept at temperatures of 24°C and 85°C. The W4S program is a washing process determined by subjecting the feathers washed after the W4 program to treatment in a centrifuge machine. The results of this program can be compared with the W4 washing results in figure 7 for analysis.

After W4 washing, it is observed that foreign substances and fatty acids in the feathers are significantly reduced by processing in a centrifuge machine. When compared with the PA data in figure 7, it is observed that the total area of the peaks covered by fatty acids and other substances in the chromatogram decreases by approximately 8 times at 24°C and approximately 5 times at 85°C. This is considered to be a result of the centrifugation process used. While the effect of centrifugation on certain types of washing is more limited, it has been observed to enhance the performance of the washing process. The more limited effect of centrifugation is likely due to the fact that the solvent cleaning process

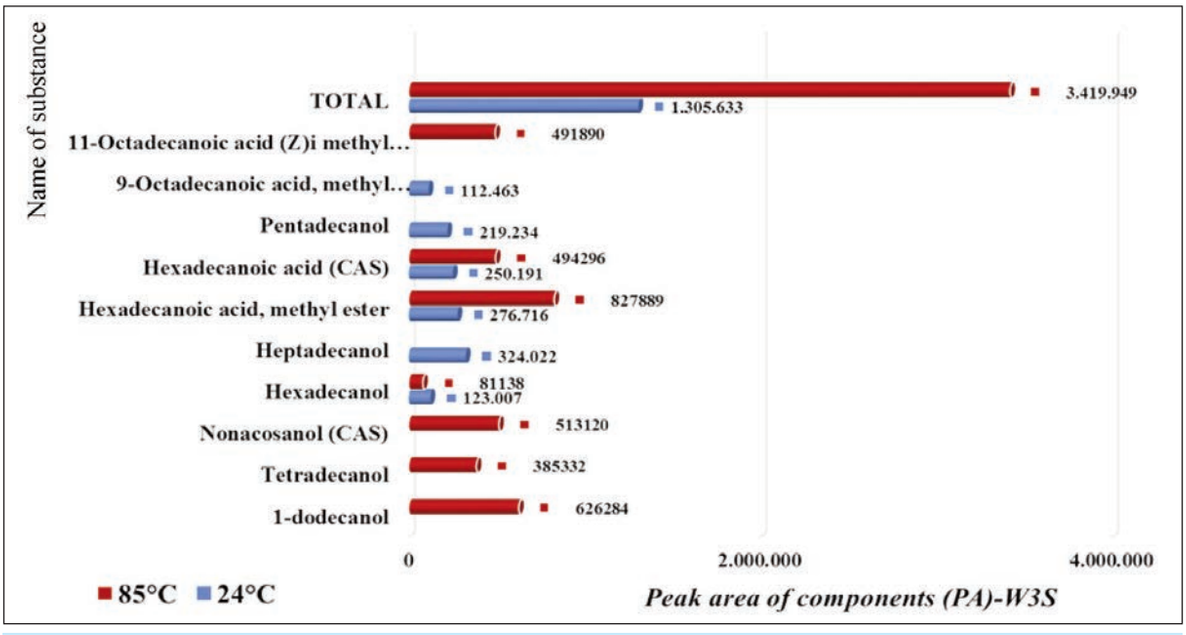


Fig. 11. GC-MS results of TFs washed according to the W3S-coded prescription

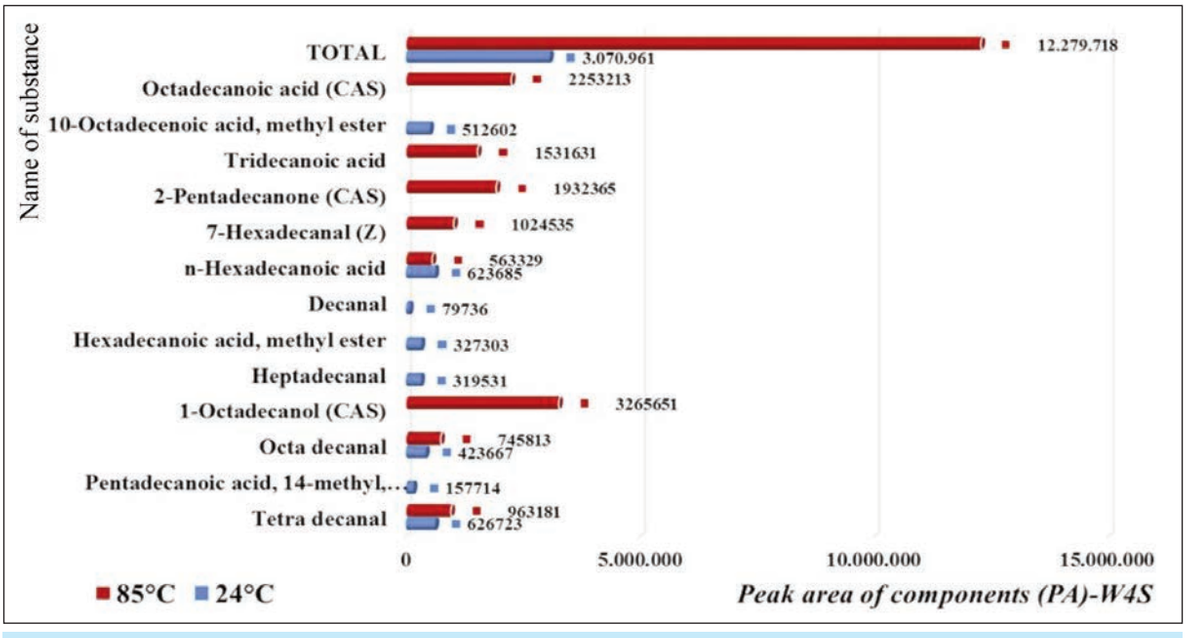


Fig. 12. GC-MS results of TFs washed according to the W4S code prescription

was performed, and no fatty acids that could be separated from the material by centrifugation and cause odour were detected.

Figure 13 shows the GC-MS analysis results of extracts obtained from feathers washed under W5S washing conditions and kept at temperatures of 24°C and 85°C. The W5S program is a wash determined by processing the feathers washed after the W5 program in a centrifuge machine. The results of this program can be compared with the W5 wash results in figure 8 for analysis.

After the W5 washing process, it can be seen that foreign substances and fatty acids in the feathers are significantly reduced by processing in a centrifuge machine. When compared with the PA data in figure 8, it is observed that the total area of the peaks covered by fatty acids and other substances in the chromatogram decreased by approximately 68% at 24°C and by approximately 88% at 85°C.

Additionally, it is observed that the total PA values at 24°C and 85°C are very close to each other. This indicates that the odour caused by the temperature difference has been reduced to minimum levels. The fact that W5S yields better results than the W5 washing program is attributed to the centrifugal processing method used.

Figure 14 shows the GC-MS analysis results of extracts obtained from feathers washed under W6S washing conditions and kept at temperatures of 24°C and 85°C. The W6S program is a wash determined

by processing the feathers washed under the W6 program in a centrifuge machine. The results of this program can be compared with the W6 wash results in figure 9 for analysis.

After the W6 washing process, it can be said that the foreign substances and fatty acids in the feathers are almost completely removed by processing them in a centrifuge machine. When compared with the total PA data in figure 9, it can be seen that the total area of the peaks covered by fatty acids and other substances in the chromatogram decreased by approximately 16% at 24°C and by approximately 66% at 85°C. Additionally, it is observed that the total PA values at 24°C and 85°C are very close to each other. This indicates that the odour caused by the temperature difference has been eliminated. The fact that W6S yielded better results than the W6 washing program is attributed to the centrifugal processing used. The W6S program was applied to remove the residues remaining on the feathers after the W6 washing process, despite the neutralisation of the fatty acids, and to obtain an odourless and clean result. When the chromatograms of the samples obtained at 24°C and 85°C in figure 14 are compared with the chromatograms of the feathers from other washes, it is observed that the total peak areas of the volatile compounds formed are minimised. Based on these data, it is observed that as temperature

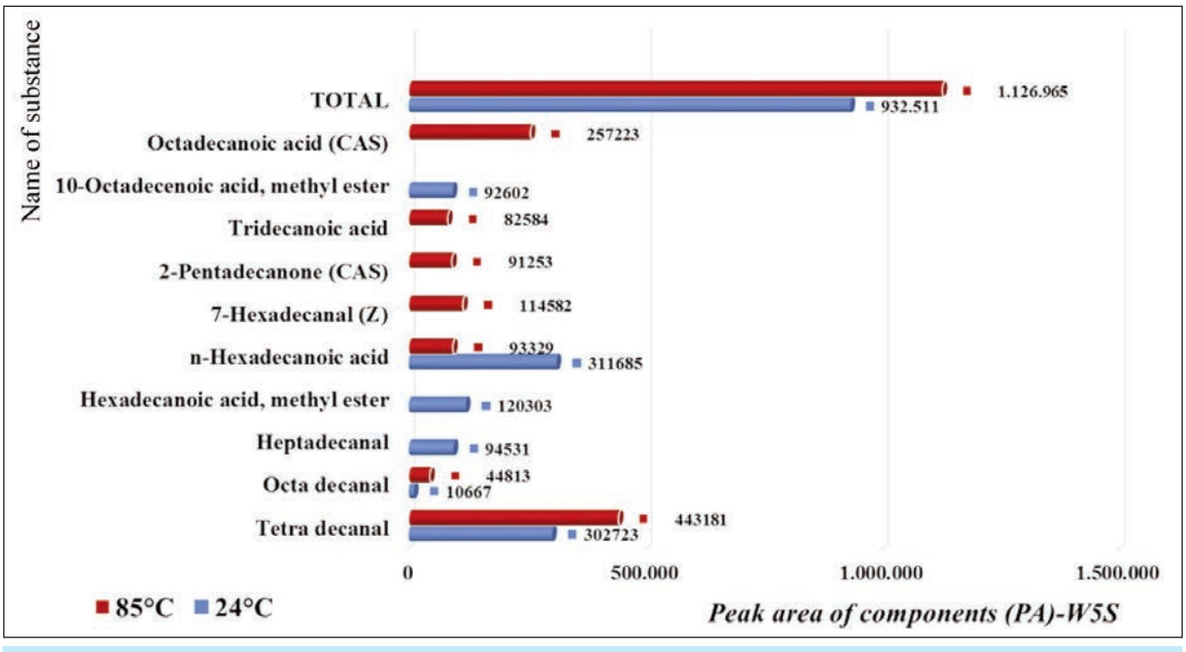


Fig. 13. GC-MS results of TFs washed according to the W5S-coded prescription

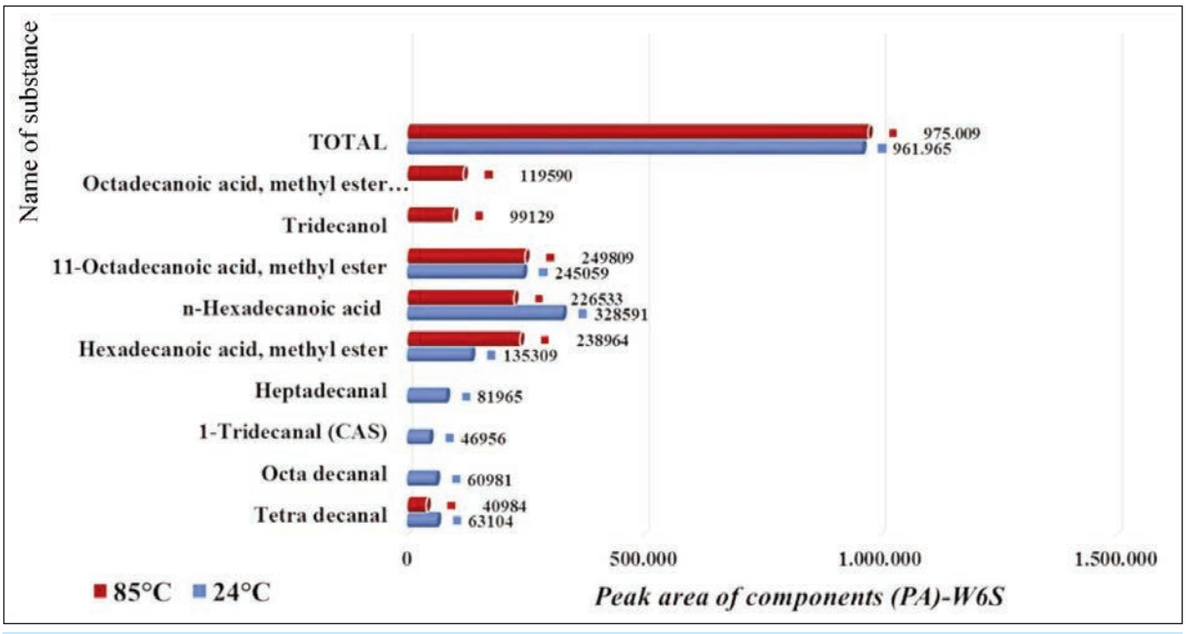


Fig. 14. GC-MS results of TFs washed according to the W6S code prescription

increases, the total peak area of the volatile compounds released appears to overlap with the total peak area of the volatile compounds released at normal temperature. This clearly indicates that the odour of TF will not increase with temperature. This has been identified as the best washing result.

CONCLUSION

Basically, animal fibres, and more specifically turkey, chicken, goose, and other bird feathers, must be washed before use. These feathers are highly susceptible to environmental influences. It is particularly important to avoid environments with high temperatures and humidity, which can damage their structure and cause them to smell. This research revealed that when cleaned feathers were stored in hot conditions or used to make materials at high temperatures, they released an unpleasant smell. Since turkey feathers are especially sensitive to environmental factors like temperature changes, 11 distinct washing techniques and programs were created to get rid of their odour. The feathers were heated to temperatures of 24°C and 85°C to extract volatile oils and fatty acids that cause the odour. Analyses were performed using a GC-MS device to identify and remove substances in the structure of feathers that cause bad odours. The analysis revealed that the primary substances responsible for the unpleasant odour are oils, fatty acids, and residues in the feathers.

- The results show that dirty feathers contain high levels of fatty acids and volatile compounds.
- It has been proven that these volatile compounds, which cause odours, can be removed depending on the type and method of washing. Some types of washing eliminate volatile compounds, while other washing methods are ineffective.
- SEM images were taken to determine the surface and internal structure of the turkey feathers after washing. The internal structure in the SEM images was observed to be intact after washing. The fact that the feathers remain intact is of great importance, especially when they are used in the manufacture of insulation materials.
- The most effective washing method was found to be the W6S program. This program consists of four stages. After washing, the amount of odour remaining on the hair has been reduced to a level that is imperceptible to humans. After washing, the total PA amount at temperatures of 24°C and 85°C is seen to be almost the same.
- According to the FTIR analyses and SEM results, no changes in the internal and external structure of the fibres were observed as a result of the washing process.

Finally, if I need to give a few basic headlines to the results of the study, I can state the following:

- The use of centrifuges for washing and disinfecting turkey feathers yields good results.
- Possible delays in the washing of protein-based animal fibres can cause odours and damage the structure.
- It is possible to remove the odour from turkey feathers by using different chemicals and washing methods.
- The best cleaning can be achieved by neutralising the fats and fatty acids in the structure of protein fibres.
- The best cleaning method for turkey feathers is pre-washing with NACIO + main washing with non-ionic soap + bleaching with NAOH + centrifuging.

I recommend this washing method to my colleagues working in the production of similar feathers and to industry professionals.

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