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Original

# Extracting Keratin from Chicken Feathers and Studying some of the Factors Affecting the Extraction Process

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**Abstract:** Chicken feather waste causes environmental and health problems, so thought was given to properly disposing of it by extracting keratin, the main component of the waste. In this research, we used two different solutions for extracting keratin, using urea and cysteine as solution (A) and sodium dodecyl sulfate as solution (B). The factors affecting the extraction method, including temperature, pH, time, and urea concentration, were studied. The optimal conditions for the extraction process were determined. The results showed that the optimal conditions for extraction, as determined by solution (A), were a temperature of 70 °C, a pH greater than 11, a reaction time of 6 hours, and a urea concentration of 8 M. Under these conditions, the yield reached 50%. For solution (B), the optimum extraction temperature was 70 °C, the duration was 2 hours, and the pH was greater than 11, yielding 39.9%. The biuret test confirmed the resulting protein material, and the protein percentage was estimated by the Kjeldahl method. Peaks at the wavenumbers of the functional bonds (N-H) and (C=O) were noticed by FTIR. DSC thermal examination also gave the glass transition point and melting point of raw feathers and extracted keratin. The research results demonstrated good effectiveness in keratin extraction and the utilization of waste materials, rather than discarding them.

*Keywords:* **Chicken feathers, cysteine, keratin extraction, Kjeldahl, keratin.**

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## 1-Introduction

Chicken feathers constitute about 5-10% of the chicken's body and are produced in large quantities by poultry farms. These feathers are disposed of by landfilling or burning, causing environmental and health problems. Therefore, it was necessary to consider ways to benefit from this waste by converting it into valuable products. Keratin is the primary component of feathers, constituting about 90% of chicken feathers (Adav et al., 2018). Chicken feather fibers are rich in protein, making it possible to extract the protein contained in them rather than wasting it. Extracted keratin can be used in multiple applications, such as wound-healing gel or producing keratin nanofibers for medical fields (He et al., 2017).

Keratin is a fibrous protein and the main component of hair, feathers, nails, wool, hooves, and horns of mammals, reptiles, and birds. It is the third most abundant polymer in nature after cellulose and chitin (Lange et al., 2016).

Keratin forms complex polymers that are insoluble in water and organic solvents and resistant to degradation by common proteolytic enzymes such as trypsin. This is due to keratin's highly oriented fibrous structure, resulting from disulfide bonds and hydrogen bonds (Meyers et al., 2008).

There are two types of keratins, α-Keratin and β-Keratin. The structure of α-Keratin is a helical coil, and this structure causes environmental problems because of its resistance to disintegration by microbes. This type of keratin is characterized by its strength, hardness, and insolubility in regular solvents (Vandebergh & Bossuyt, 2012). α-Keratin contains large amounts of hydrophobic amino acids such as methionine, phenylalanine, valine, isoleucine, and alanine (Kannahi & Ancy, 2012). Depending on its sulfur content, it is classified into soft keratin and hard keratin (Balakumar et al., 2013). β-Keratin is a structural protein found in reptiles and birds. It contains a high percentage of cysteine, which forms disulfide bonds that make it solid and highly resistant to disintegration. β-Keratin is a parallel lamella that is connected (Greenwold & Sawyer, 2013). There are about 80-90% β-Keratin in a mature feather, and the molecular weight of keratin proteins usually ranges between 10-14 kDa (Strasser et al., 2015).

There are several ways to extract keratin from materials containing keratin: the chemical method includes reduction, oxidation, alkaline hydrolysis, and extraction using ionic liquids (Shavandi et al., 2017). Extraction using enzymatic and biological methods involves extraction using Gram-positive bacteria, Gram-negative bacteria, or saprophytic and parasitic fungi (Ma et al., 2016). Extraction using microwave radiation (Zoccola et al., 2012). and extraction using steam and water pressure (Tonin et al., 2006).

Many researchers have studied the extraction of keratin from chicken feathers for years, but the factors affecting the extraction process have not been thoroughly discussed. The chemical method using reducing agents was employed in this research because the reducing agent used is environmentally friendly. Through its use, it is possible to control the breakage of disulfide bonds. Most importantly, the resulting extract possesses desirable properties, making it suitable for use in the production of protein fibers and in the manufacture of membranes. This method is considered low-cost and straightforward. Some factors that affect keratin extraction were studied. In this research, we present an approach to avoid environmental pollution that results from the random disposal of chicken feathers.

## 2. Methodology

### *2.1. Collecting and Preparing Chicken Feathers*

Feathers were collected from poultry farms, then washed and cleaned of dirt and dust using soap and water. They were sterilized with ethanol to remove any germs, microbes, and remaining greasy substances. Afterward, they were rewashed and dried in the sun. The feather fibers were separated from the main shaft and kept in a sealed bag until work began.

### *2.2. Extraction Methods*

The extraction was performed in an alkaline medium using solution A (containing urea and cysteine) and solution B (containing urea and sodium dodecyl sulfate, SDS).

#### *2.2.1. Extraction Method Using Solution A*

The extraction process was carried out as follows: A urea solution was prepared with different concentrations (5-6-7-8) M, and cysteine was added to it at a rate of 10% by weight of chicken feathers. The pH was adjusted to different values (9, 10, 11, and 12) using sodium hydroxide (2 M). The feathers were then added to the solution at a ratio of 1 to 20 to immerse them completely, and the mixture was heated with stirring at different temperatures (40-50-60-70) °C to determine the optimal temperature over periods ranging from two hours to 6 hours, during which the feathers dissolved. Filtration was carried out to remove any insoluble residue using filter paper (MN

126/70) under normal conditions, which took (1-2) hours without vacuum. The solution obtained after filtration was centrifuged at 4000 rpm for 15 minutes. Keratin was precipitated using hydrochloric acid (1 M) until the pH reached a value between 4 and 5.5, which is the electrical neutralization point of the keratin protein, and sodium sulfate was added until complete precipitation occurred. The resulting precipitate was washed with distilled water three times and dried in a freezer at a temperature of (-65 °C) and a pressure of 4 mbar until completely dry, then ground to obtain powder. The resulting yield was then calculated based on the weight of the dried powder.

### *2.2.2. Extraction Method Using Solution B (Urea with Sodium Dodecyl Sulfate*

An aqueous solution containing 8 M urea and SDS was prepared, and NaOH (0.5 M) was added drop by drop to achieve different pH values (9-10-11-12). Feathers were then added to the prepared solution. The mixture was heated for varied periods and at various temperatures (40-50-60-70) °C with constant stirring. The solution was filtered using filter paper (MN 126/70) under normal conditions which took 1-2 hours without vacuum, and the pH was adjusted using 1 M hydrochloric acid. Next, the salts were removed from the mixture through dialysis using dialysis bags (cellulose tubes) immersed in distilled water, with the water changed multiple times throughout the day for three days. Finally, the sample was dried in a lyophilizer to obtain dry keratin.

### *2.2.3 The Effect of Various Factors on Keratin Extraction*

#### 2.2.3.1 The Effect of Temperature, pH, Urea Concentration, and Reaction Time on the Yield of Keratin Produced Using Solution (A)

The experiment was conducted to study the effect of temperature under the conditions shown in Table 1.

Table 1: Conditions for studying the temperature effect.

| | |
|---|---|
| Chicken feather mass | 5 g |
| Cysteine | 10% (w/w) of chicken feather |
| pH | 11.5 |
| Urea concentration | 8 M |
| Time of reaction | 6 h |

The experiment was conducted to study the effect of pH under the conditions shown in Table 2.

Table 2. Conditions for studying the pH effect.

| | |
|---|---|
| Chicken feather mass | 5 g |
| Cysteine | 10% (w/w) of chicken feather |
| Temperature | 70 °C |
| Urea concentration | 8 M |
| Time of reaction | 6 h |

The experiment was conducted to study the effect of time reaction under the conditions shown in Table 3.

Table 3. Conditions for studying the time reaction effect.

| | |
|---|---|
| Chicken feather mass | 5 g |
| Cysteine | 10% (w/w) of chicken feather |
| pH | 11.5 |
| Urea concentration | 8 M |
| Temperature | 70 °C |

The experiment was conducted to study the effect of time on reaction under the conditions shown in Table 4.

Table 4. Conditions for studying the effect of urea concentration.

| | |
|---|---|
| Chicken feather mass | 5 g |
| Cysteine | 10% (w/w) of chicken feather |
| pH | 11.5 |
| Time of reaction | 6 h |
| Temperature | 70 °C |

#### 2.2.3.2 The effect of temperature, pH, and reaction time on the obtained yield using solution (B)

The experiment was conducted to study the effect of temperature under the conditions shown in Table 5.

Table 5. Conditions for studying the temperature effect.

| | |
|---|---|
| Chicken feather mass | 5 g |
| SDS (sodium dodecyl sulphate) | 10% (w/w) of chicken feather |
| pH | 11.5 |
| Urea concentration | 8 M |
| Time of reaction | 2 h |

The experiment was conducted to study the effect of pH under the conditions shown in Table 6.

Table 6. Conditions for studying the pH effect.

| | |
|---|---|
| Chicken feather mass | 5 g |
| SDS (sodium dodecyl sulphate) | 10% (w/w) of chicken feather |
| Temperature | 70 °C |
| Urea concentration | 8 M |
| Time of reaction | 2 h |

The experiment was conducted to study the effect of time reaction under the conditions shown in Table 7.

Table 7. Conditions for studying the reaction time effect.

| | |
|---|---|
| Chicken feather mass | 5 g |
| SDS (sodium dodecyl sulphate) | 10% (w/w) of chicken feather |
| Temperature | 70 °C |
| Urea concentration | 8 M |
| pH | 11.5 |

## 3. Analysis

### 3.1 Biuret Test

The principle of the biuret test is the ability of copper (II) ions to form a violet complex with peptide bonds in alkaline media. This test confirms the presence of proteins in the sample. A small amount of the extracted powder is taken and placed in a dry test tube. Then, a few drops of NaOH solution (10%) are added, followed by a few drops of CuSO4 solution (10%) to the sample test tube (Pandey et al., 2021). The biuret test is used to determine whether the resulting extract is a protein substance, as it is specifically designed to detect proteins.

### 3.2 Kjeldahl Test to Estimate the Percentage of Protein in the Extracted Sample

This test is used to estimate the percentage of protein. The percentage of protein in the sample is calculated by determining the percentage of nitrogen in the sample.

The percentage of nitrogen in the sample is calculated from Equation (1)

$$N\%=(Vx0.014xN)x100/m \qquad (1)$$

The percentage of protein in the sample is calculated from Equation (2)

$$P\%=N\%\ x\ Factor \qquad (2)$$

Where *V* is the volume consumed for the titration (ml), *N* is the normality of the hydrochloric acid used in the titration (*N*), m is the sample weight (g), *N%* is the percentage of nitrogen in the sample, and *P%* is the percentage of protein in the sample. Each protein substance has a factor, and if the exact composition of the protein is not known, a general factor of 6.25 can be used (McSweeney & McNamara, 2022). Since the keratin was extracted and its composition is unknown, a factor of 6.25 was used to estimate the protein content.

### 3.3 FTIR Infrared Spectroscopy Test of Prepared Samples

The chemical composition of the extracted keratin and raw feathers was analyzed using a Fourier transform infrared (FTIR) spectrometer manufactured by Shimadzu. The spectra were collected at a wavenumber range of (4000-500) using the transmission mode and 4 resolution.

### 3.4 Differential Scanning Calorimetry

The raw feather sample and extracted keratin A were analyzed on a Differential Scanning Calorimetry device (DSC131) from SETARAM Company, made in France. The samples were heated from 25 °C to 400 °C under a continuous nitrogen purge at a heating rate of 10 °C/min.

## 4. Results and Discussion

### 4.1 The Effect of Various Factors on Keratin Extraction

As shown in Figure 1a and Figure 2a, temperature has a significant impact on the extraction process. Increasing the temperature in both extraction methods led to an increase in the resulting yield because the high temperature in alkaline media facilitates the dissolution of the disulfide bonds in the keratin of the feathers. When the temperature was raised from 40 °C to 70 °C, the yield increased by 41.4% when using solution A and 52.49% when using solution B.

While the average pH value played the most significant role after temperature in influencing the resulting yield, the yield increased by 86.2% when the average pH value was increased from 9 to 12 in solution A, as shown in Figure 1b, and by 67.31% when using solution B, as shown in Figure 2b. This can be attributed to an increase in the alkalinity of the solution, thus enhancing the disintegration of the disulfide bonds present in the keratin of the feathers and subsequently increasing the disintegration of the peptide chains, as observed by the complete dissolution of chicken feathers. The reaction container was placed in a water bath to maintain a temperature of 70 °C.

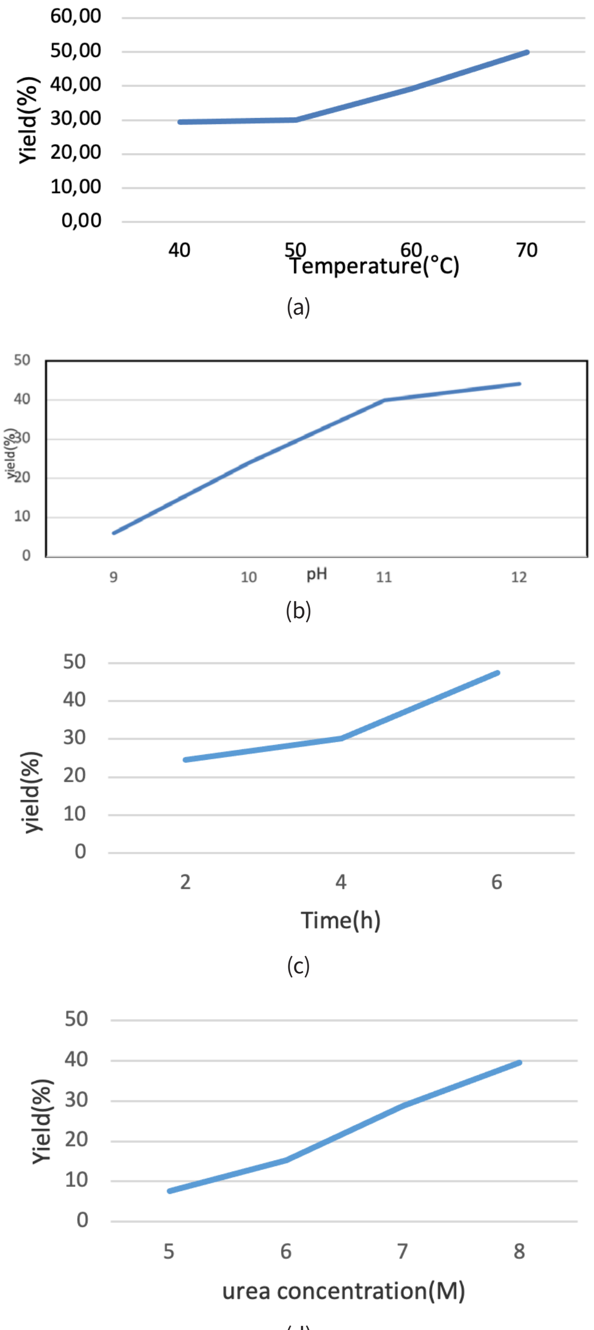

Figure 1. The effect of various factors on keratin extraction using solution A. (a) effect of temperature, (b) effect of pH, (c) effect of time, (d) effect of urea concentration.

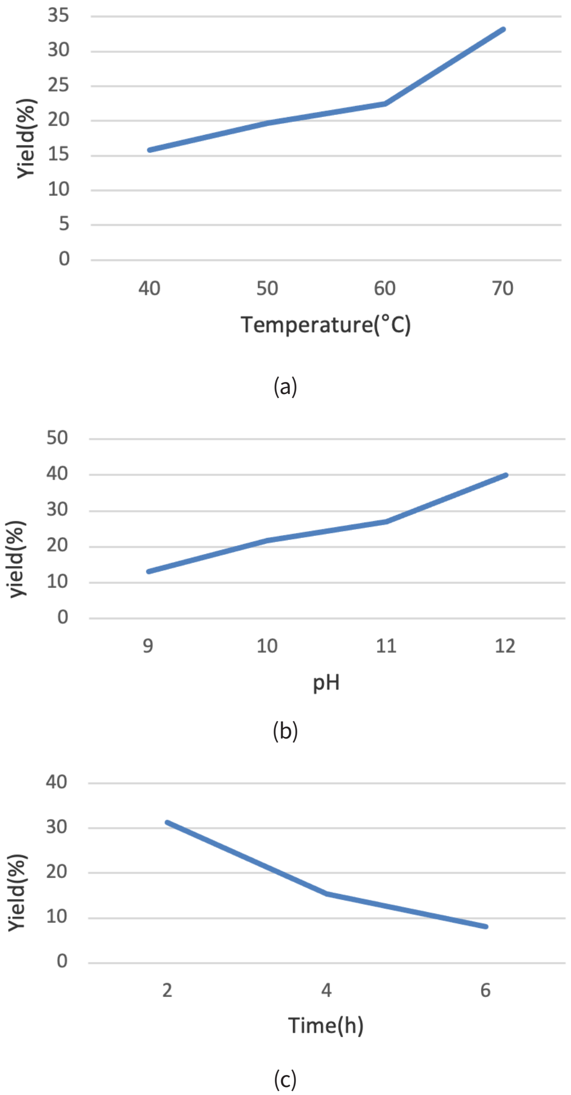

Figure 2. The effect of various factors on keratin extraction using solution B. (a) effect of temperature, (b) effect of pH, (c) effect of time.

Increasing the reaction time led to an increase in the resulting yield, as shown in Figure 1c. The yield increased by 48.12% when the sample was run for a longer time, from 2 hours to 6 hours, using solution A. This is due to the dissociation of more peptide chains and thus an increase in the amount of dissolved protein before it precipitates. As for solution B, the yield was highest at the shortest reaction time, as the yield decreased when the reaction time increased by 74.04% when the reaction time increased from 2 to 6 hours, as shown in Figure 2c. This may be due to the destruction of the protein structure as the reaction time increases, thus precipitating a small amount of protein. Extraction was carried out during different time periods, starting from 2 hours and gradually increasing by 2 hours each time, to determine the effect of time on the extraction yield. During the experiment, we obtained the same yield at 6 and 8 hours, so it was sufficient to extract for up to 6 hours.

The use of urea in high concentrations, up to 8 M, led to an increase in the resulting yield, as shown in Figure 1d. The yield increased when the urea concentration increased from 5 M to 8 M by 80.85% because urea is used as a catalyst for breaking disulfide bonds. It destroys the peptide chains, and then these chains can be reshaped, preserving the structure of the keratin after extraction. Based on the findings from the experiment using solution A, the concentration of 8 M was adopted for extraction using solution B when studying the effects of the remaining factors of temperature, reaction time, and pH.

Based on the above, it was concluded that the best yield of extracted keratin was achieved at a temperature of 70 °C, a reaction time of 6 hours, a pH range of 11 to 12, and a urea concentration of 8 M for solution A. The best conditions for extracting keratin for solution B were extraction at a temperature of 70 °C, a reaction time of 2 hours, and a pH between 11 and 12. Thus, these conditions were adopted for extracting keratin and for subsequent tests. The extracted keratin under the best conditions using solution A is shown in Figure 3.

Figure 3. Extracted keratin using solution (A).

## 4.2 Biuret Test Results

After adding a few drops of NaOH solution to the extracted powder, the dissolution of the substance began slightly. Then a few drops of copper sulfate solution were added, resulting in a color change to violet. This change occurred due to a complex formation between copper ions and the protein present in the sample, as shown in the following diagram:

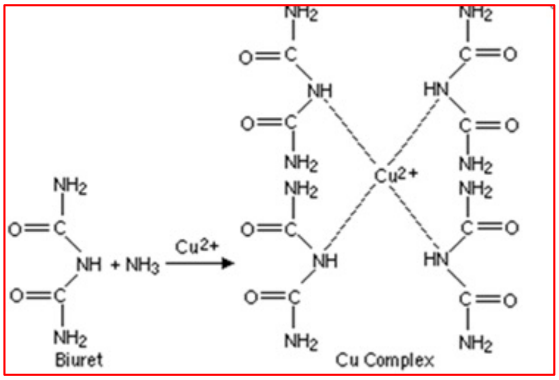

Figure 4. Chemical diagram of the biuret tests.

## 4.3 Kjeldahl Test Results

Table 8 shows that raw feathers contain about 66.70% protein in their composition, while the extracted keratin using solution A achieved the highest percentage of protein, reaching 87.71%.

Table 8. Estimation of protein percentage according to the Kjeldahl test.

| Sample number | Solution used for extraction | Protein percentage |
|---|---|---|
| 1 | Cleaned and prepared raw feathers | 66.70% |
| 2 | Extracted keratin using solution A | 87.71% |
| 3 | Extracted keratin using solution B | 60.16% |

## 4.4 FTIR results

As shown in Figure. 4 the presence of distinct peaks attributed to peptide bonds (-CONH) can be observed in the three diagrams, which can be classified as amide A, primary, secondary, or tertiary. For the sample of raw feathers in Figure 4, a clear peak is noticeable at a wavenumber of 3300 $cm^{-1}$, indicating the presence of (O-H) and (N-H) bonds and amide A. Additionally, a peak at 2927.94 $cm^{-1}$ is observed, which corresponds to the symmetrical vibration of the CH2 group and the C-H bond. The peak at 1650 $cm^{-1}$ indicates the presence of secondary amide, representing a mixture of the α-helix and the β-sheet present in the structure of feathers, with this wavenumber explicitly associated with the carbonyl group (C=O). A weak transition at 1232.51 $cm^{-1}$ indicates the tertiary amide, along with the presence of an extended (C-N) and (C-C) stretch bond.

Similarly, in Figure 4, the same peaks are observed at approximately the same wavenumbers in both extracted keratin samples. A peak at 3400 $cm^{-1}$ indicates the presence of the (O-H) group and amide A in both extracted keratin samples. The peak at 2900 $cm^{-1}$ signifies the (C-H) bond, while the sharp peak at 1650 $cm^{-1}$ indicates the secondary amide and the carbonyl group (C=O). Weak transitions at 1200 $cm^{-1}$ and 1225 $cm^{-1}$ indicate the tertiary amide and (C-N), as well as the (C=O) and (C-C) extended bonds, respectively.

By comparing the structure of the keratin found in the feathers in Figure 5 from reference (Saha et al., 2018), it can be confirmed that the functional groups and chemical bonds present in both extracted keratin samples are consistent with keratin. This confirms the success and efficiency of the extraction method and validates the identification of keratin protein.

From the FTIR charts, it can be concluded that the chemical method used to extract keratin from chicken feathers in this research did not alter the composition of the protein present in the raw feathers. Thus, this method (solution A and solution B) was deemed suitable for extracting keratin from chicken feathers.

### *4.5 DSC Results*

Figure 6 shows the temperature changes for the raw feather sample and the extracted keratin. There is the presence of an endothermic peak at 60.11 °C, indicating the glass transition temperature of the raw feathers. Additionally, there is an endothermic peak at 278.49 °C, representing the melting point of the raw feathers, where the α structure within the feathers begins to melt, leading to complete disintegration at 319.78 °C.

Regarding the DSC diagram of the extracted keratin, an endothermic peak is observedat 62.74 °C, signifying the glass transition temperature. Moreover, the melting point is recorded at 234.84 °C, which is lower than the melting point of raw feathers (278.49 °C). From the above, it is evident that the extraction method significantly influences the thermal behavior of the extracted keratin (Alahyaribeik & Ullah, 2020).

From the results, it can be concluded that chicken feather fibers are rich in keratin protein. Instead of discarding feathers in a landfill, burning it, or burying it, we can benefit from it by extracting the keratin present in the composition of chicken feathers. The keratin content in the feathers used in this research was estimated to be approximately 66.70% based on the Kjeldahl test.

It was concluded from the results that the best extraction conditions for solution A, which gave the highest yield (50%), were at a temperature of 70 °C, a reaction time of 6 hours, a pH greater than 11, and a urea concentration

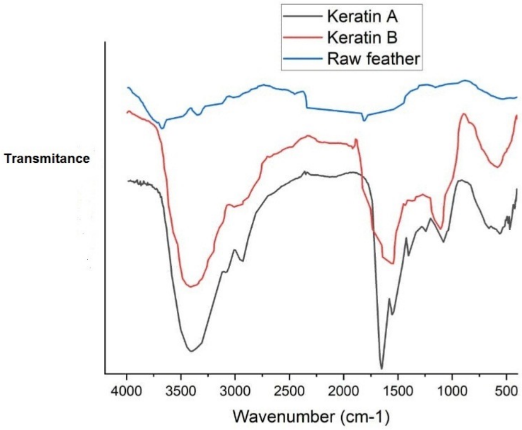

Figure 4. FTIR for raw feathers and extracted keratin using solution A (Keratin A) and extracted keratin using solution B (Keratin B).

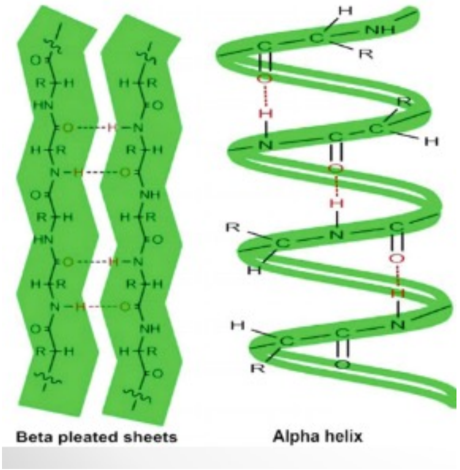

Figure 5. Keratin structure [16].

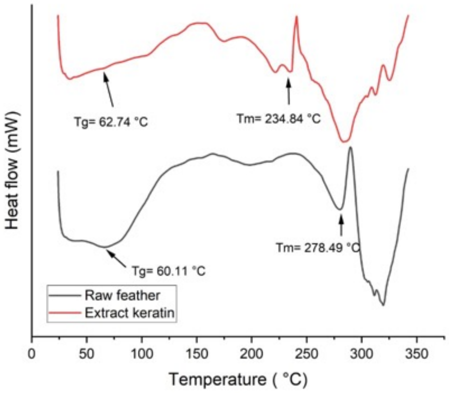

Figure 6. DSC for raw feathers and extracted keratin.

of 8 M. While the highest value of yield using solution B was 39.9% at 70 °C, reaction time 2 hours and pH greater than 11. The percentage of protein in the samples extracted was 87.71% using solution A, while the percentage was 60.16% for the sample extracted using solution B.

The residue of the extraction reaction is a mixture of dissolved salts (urea and cysteine) that separate from the protein solution after the dialysis process. This reside can be used as a chemical fertilizer for the soil.

The results of the experiments also confirmed the efficiency of the extraction process, the tests confirmed that the extracted material was a protein through the biuret test. Additionally, the extracted material was verified through FTIR spectroscopy of the raw feather sample and the extracted keratin and compared with the keratin found in chicken feathers. This comparison revealed the presence of the same chemical bonds and functional groups, confirming that the resulting material is a keratin protein and indicating that the extraction process preserved the protein's basic structure.

It was also observed from the DSC curve that the extraction process significantly affects the thermal behavior of the raw feather sample and the extracted keratin. Comparing solutions A and B, it was observed that both solutions yielded good results and return at almost the same cost. However, through experimentation in the laboratory, it was observed that the extraction using solution A yielded keratin with greater consistency and stability than the keratin extracted using solution B.

Environmental sustainability is the focus of most countries, so this work is essential because it provides a good idea for the proper disposal of waste (chicken feathers) and the preservation of the environment.

## Conclusions

Chicken feathers are a cheap and renewable source of protein. Instead of discarding them in a landfill or burning them, the keratin contained in them can be extracted in a simple and environmentally friendly way. This represents a promising future as it preserves the environment and achieves abundant economic profit by using this extracted keratin as a cosmetic product for hair, in wound-healing gels, in nanofiber production, and in other biological applications. The results of this research indicate the possibility of obtaining a product of important economic value from chicken feather waste.

In this research, a yield of 50% was achieved, which is very good, and the reaction residues were utilized as a chemical fertilizer for the soil.

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## Conflict of interest

The authors do not have any conflict of interest.

## References

Adav, S. S., Subbaiaih, R. S., Kerk, S. K., Lee, A. Y., Lai, H. Y., Ng, K. W., ... & Schmidtchen, A. (2018). Studies on the proteome of human hair-identification of histones and deamidated keratins. *Scientific reports*, *8*(1), 1599.
https://doi.org/10.1038/s41598-018-20041-9

Alahyaribeik, S., & Ullah, A. (2020). Methods of keratin extraction from poultry feathers and their effects on antioxidant activity of extracted keratin. *International journal of biological macromolecules*, *148*, 449-456.
https://doi.org/10.1016/j.ijbiomac.2020.01.144

Balakumar, S., Mahesh, N., Arunkumar, M., Sivakumar, R., & Hemambujavalli, V. (2013). Optimization of keratinase production by keratinolytic organisms under submerged fermentation. *Optimization*, 5(3), 1294-1300.

Greenwold, M. J., & Sawyer, R. H. (2013). Molecular evolution and expression of archosaurian β-keratins: Diversification and expansion of archosaurian β-keratins and the origin of feather β-keratins. *Journal of Experimental Zoology Part B: Molecular and Developmental Evolution*, *320*(6), 393-405.
https://doi.org/10.1002/jez.b.22514

He, M., Zhang, B., Dou, Y., Yin, G., Cui, Y., & Chen, X. (2017). Fabrication and characterization of electrospun feather keratin/poly (vinyl alcohol) composite nanofibers. *RSC advances*, *7*(16), 9854-9861.
https://doi.org/10.1039/C6RA25009B

Kannahi, M., & Ancy, R. J. (2012). Keratin degradation and enzyme producing ability of Aspergillus flavus and Fusarium solani from soil. *J Chem Pharm Res*, 4, 3245-3248.

Lange, L., Huang, Y., & Busk, P. K. (2016). Microbial decomposition of keratin in nature—a new hypothesis of industrial relevance. *Applied microbiology and biotechnology*, *100*(5), 2083-2096.
https://doi.org/10.1007/s00253-015-7262-1

Ma, B., Qiao, X., Hou, X., & Yang, Y. (2016). Pure keratin membrane and fibers from chicken feather. *International journal of biological macromolecules*, *89*, 614-621.
https://doi.org/10.1016/j.ijbiomac.2016.04.039

McSweeney., L. H. P & McNamara., P. J. (2022). Proximate and Other Chemical Analyses. Encyclopedia of Dairy Sciences (Third Edition). Department of Food Science and Nutrition.

Meyers, M. A., Chen, P. Y., Lin, A. Y. M., & Seki, Y. (2008). Biological materials: Structure and mechanical properties. *Progress in materials science*, *53*(1), 1-206.
https://doi.org/10.1016/j.pmatsci.2007.05.002

Pandey, S., Goswami, S. K., & Jain, B. P. (2021). *Protocols in Biochemistry and Clinical Biochemistry*. Academic Press.

Saha, S., Arshad, M., Zubair, M., & Ullah, A. (2018). Keratin as a Biopolymer. In *Keratin as a protein biopolymer: extraction from waste biomass and applications* (pp. 163-185). Cham: Springer International Publishing.
https//doi.org/10.1007/978-3-030-02901-2_6

Shavandi, A., Silva, T. H., Bekhit, A. A., & Bekhit, A. E. D. A. (2017). Keratin: dissolution, extraction and biomedical application. *Biomaterials science*, *5*(9), 1699-1735.
https//doi.org/10.1039/C7BM00411G

Strasser, B., Mlitz, V., Hermann, M., Tschachler, E., & Eckhart, L. (2015). Convergent evolution of cysteine-rich proteins in feathers and hair. *BMC evolutionary biology*, *15*(1), 82.
https://doi.org/10.1186/s12862-015-0360-y

Tonin, C., Zoccola, M., Aluigi, A., Varesano, A., Montarsolo, A., Vineis, C., & Zimbardi, F. (2006). Study on the conversion of wool keratin by steam explosion. *Biomacromolecules*, *7*(12), 3499-3504.
https://doi.org/10.1021/bm060597w

Vandebergh, W., & Bossuyt, F. (2012). Radiation and functional diversification of alpha keratins during early vertebrate evolution. *Molecular biology and evolution*, *29*(3), 995-1004.
https://doi.org/10.1093/molbev/msr269

Zoccola, M., Aluigi, A., Patrucco, A., Vineis, C., Forlini, F., Locatelli, P., ... & Tonin, C. (2012). Microwave-assisted chemical-free hydrolysis of wool keratin. *Textile Research Journal*, *82*(19), 2006-2018.
https://doi.org/10.1177/0040517512452948