Potential development of poultry feather waste resources as raw material in industry: A review

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Abstract. Feather waste is a type of livestock by-product which is quite abundant. Feather waste production is influenced by the amount of poultry slaughter. In Indonesia, the poultry population occupies the highest number compared to other livestock populations. The large amount of feather waste production will also trigger livestock waste production. Various attempts have been made by researchers and industry to process and utilize this waste. Increasing the added value of feather waste is expected to be able to contribute to reducing the rate of waste production. Feather waste has been widely used in the poultry industry as animal feeds ingredients. In addition, Feather waste has also been used as a medium in sports activities and furniture raw materials through the production of home industries. Currently, the development of research by scientists related to alternatives to the use of feather waste has been growing rapidly. Various challenges to reduce the production of feather waste have been carried out to create environmentally friendly products. The purpose of this review was aims to evaluate the development of the latest research technology related to the potential and use of poultry feather waste as raw material in the industrial field.

1. Introduction
Globally, feathers are a type of waste that is quite abundant and has a very low economic value. This waste has been used as animal feeds ingredients. Feathers are processed into feather meal by using autoclaves [1,2]. The poultry industry disposes billions of tons of feather waste every year. Most of the substrate in the form of keratinization is thrown into landfills or burned. This causes the use of energy consumption to be high and environmental pollution. Keratin waste has a high protein content, but is very difficult to degrade. This waste is very detrimental and not environmentally friendly. The physical and chemical treatment given in treating keratin waste can cause damage to essential amino acid components. This can reduce the quality and digestibility of the protein.

The use of keratinolytic microorganisms are very important to degrading the insoluble keratin of feathers to produce nutritious and cost-effective animal feed ingredients. Microbial degradation by keratinase which plays a major role in the process of biodegradation of hairy waste [3]. In India, around 350 million tons of fur waste has been produced from the poultry industry every year. The resulting keratin becomes a serious problem and is a concern as one of the causes of environmental pollution [4,5]. Each bird has around 125g feathers. Around the world, every week approximately 400 million chickens are processed, so the potential waste produced can reach 5 million tons [6].
2. Potential production of feather waste
Globally, feather waste is obtained from poultry which is the main consumption ingredient of the community [7]. A number of 5-7% from the total mass of adult chickens is a feather component. This amount is removed as a by-product. Feather waste consists of 90% of the components that are very difficult to degrade. Base on the high protein content, this waste needs to have a great opportunity to be developed [8-10]. Based on the type of poultry, chicken has ranks first as a producer of feather waste, although meat from turkey and duck is consumed the most [11]. Every year millions of tons of feather waste is produced worldwide by the poultry industry. This number has been increasing continuously along with the increase in poultry meat production. This will certainly be an environmental burden. Pollution will increase which will affect human health [12,13]. Research to produce the latest products related to reuse and utilization of feather waste has become very important and has been growing rapidly [14-16]. In England, management of feather waste into feather meal is still carried out conventionally using autoclaves. The proceeds from the production of feather meal have been exported to Eastern Europe and Russia. Feather meal is animal feed material with low economic value but has high protein content [17]. In addition to feather, by-products from livestock urine waste have also been developed as liquid fertilizer [18].

3. Tissue structure of feather
The tissue structure that makes up the feathers is presented in figure 1 [19]. The rachis is the core of the structure in feathers. The rachis is rigid and on the side resembles a propeller and comb. Feathers have strong, insoluble structures and their proteins form filaments. Protein in feathers is keratin which has similarities with proteins in horns and nails. Keratin protein is dominated by \(\alpha\)-keratin [20]. In addition, feathers also have \(\beta\)-keratin groups which are easily degraded at low temperatures but have high strength [21]. The results of the analysis using Thermal Gravimetric Analysis (TGA) showed that the degradation process in atmospheric \(\text{N}_2\) can occur at a temperature of 180 \(\degree\)C [22].

![Figure 1. Tissue structure of a feather [19]](image)

The development of the economic cycle is a critical point. The human population in the world is increasing and there is an unsustainable use of natural resources. Therefore, continuous production of waste materials is needed [23]. Keratin can be extracted from all parts of chicken feather waste using sodium disulfide and l-cysteine. The yield that can be extracted from each ingredient is 88% and 66%. The ratio between the mass of the hair processed with a reducing agent is 1:20. The reaction temperature applied was 40 \(\degree\)C for 6 hours (figure 2) [24]. Keratin is a type of small protein with a relatively more uniform size. This protein has a molecular mass of 10-36 kg/mol [25-27].
Keratin is a type of fibrous protein and the amount is very abundant in the environment. Keratin is the main constituent component in hair, feathers, nails, wool and horns in mammals, reptiles and birds. Keratin is the third largest polymer type after cellulose and chitin. Keratin has biodegradability and biocompatibility properties that are quite unique and have non-toxic properties. Structurally, keratin can be modified and developed into several forms such as gels, films and nano and micro particles. This stability is caused by a large number of intra and intermolecular disulfide crosslinking. This greatly influences the level of strength and stiffness caused by the high proportion of cysteine residues in the polypeptide and is bound together by disulfide bonds [28]. Therefore, keratin can be used as a

![Figure 2. Chart of the process of extracting keratin from chicken feathers [24]](image_url)

**Table 1.** Characteristics of board fiber that produced from feather waste in various pressurized heating conditions [1].

| Pressing Conditions | Properties |
|---------------------|------------|
| Temperature °C | Pressure MPa | Time (s) | Density (g.cm⁻³) | Porosity % | Tensile Strength (MPa) | Young’s Modulus (GPa) | Elongation at fracture (%) |
|                    |            |          |                |          |                       |                      |                           |
| 13                  | 6          | 6        | 0.66           | 41.1     | 8.0                   | 0.50                 | 1                          |
| 14                  | 6          | 6        | 0.71           | 36.6     | 14.5                  | 1.28                 | 7                          |
| 15                  | 6          | 6        | 0.73           | 34.8     | 17.3                  | 1.44                 | 9                          |
| 16                  | 6          | 6        | 0.74           | 33.9     | 16.8                  | 1.52                 | 6                          |
| 17                  | 6          | 6        | 0.68           | 39.3     | 14.0                  | 1.40                 | 5                          |
| 18                  | 6          | 6        | 0.67           | 40.2     | 12.3                  | 1.36                 | 2                          |
| 19                  | 6          | 6        | 0.72           | 35.7     | 11.9                  | 1.46                 | 1                          |
| 15                  | 2          | 6        | 0.70           | 37.5     | 14.0                  | 1.13                 | 7                          |
| 15                  | 4          | 6        | 0.73           | 34.8     | 15.4                  | 1.37                 | 5                          |
| 15                  | 6          | 6        | 0.77           | 31.3     | 17.9                  | 1.74                 | 5                          |
| 15                  | 8          | 6        | 0.77           | 31.3     | 15.2                  | 1.73                 | 5                          |
| 15                  | 1          | 6        | 0.79           | 29.5     | 16.0                  | 1.66                 | 7                          |
source of the latest and sustainable raw materials to meet human needs [29]. Keratin has been widely applied in many industries, such as: chemical, animal feed, pharmaceutical, biomedical, cosmetic and composite material industries [30]. These properties cause keratin to have insoluble properties in polar solutions such as water, weak acids and weak bases [31]. However, cysteine units can be reduced, oxidized and hydrolyzed [32,33].

4. Application of microorganisms in the processing of feather waste
Keratin is a type of structural protein that is insoluble, resistant to microbial degradation and proteolytic enzymes. The stability is caused by the presence of cross bonds from disulfide bonds, hydrogen bonds, and hydrophobic interactions. Keratin molecules have two forms of helical bonds, namely α-keratin (hair, nails, horns) and β-keratin (feathers, scales, beaks, claws) [34,35]. Keratin is insoluble, mechanically stable and generally resistant to proteolytic enzymes and chemical compounds [36]. Slaughterhouse waste is the largest producer of keratin ingredients obtained from feather waste. The amount reaches 91% β-keratin [37,38]. Around the world, the amount of feather waste reaches five million tons per day. The waste is generally disposed of in a landfill and burned in an incinerator. This condition causes a very large amount of environmental pollution [39,40].

Keratinase is a type of proteolytic enzyme that can be used to degrade keratin proteins. This enzyme received great attention for scientists because it can reduce the level of environmental pollution caused by feather waste. One type of bacteria that has potential as a producer of the enzyme keratinase is *Bacillus licheniformis ALW1*. The optimization results showed that this bacterium was able to increase the biosynthesis of keratinase to 72.2U/ml (2.9-fold). The coarse extracellular keratinase enzyme that is produced is optimally active at pH 8.0 and temperature 65 °C with the amount of soluble keratin production 0.7%. The resulting crude enzyme can degrade up to 63% [41]. The bacterium *Bacillus subtilis FNCC 0059* can increase the digestibility of broiler feather meal by up to 68% [42].

**Figure 3.** Comparison of the keratin response of several types of material in the production of keratinase by the bacterial activity of *B. licheniformis ALW1* (A); Effect of differences in feather concentration (%) on the production of the enzyme keratinase (B); Effect of temperature differences on the production of the enzyme keratinase (C)
Based on figure 3A, it can be seen that feather is the best substrate for *B. licheniformis ALW1* to produce keratinase of 25.3U/mL compared to other materials (wool, hair, nails and horns). Some of them can also produce keratinase up to (17.4U/mL) in the hair. This shows that *Bacillus licheniformis ALW1* is able to utilize α-keratin and β-keratin to produce the enzyme keratinase. Figure 3B shows that the feather concentration of 1%, *Bacillus licheniformis ALW1* is able to produce the highest keratinase enzyme (Figure 3B). Based on the effect of temperature, it can be seen that the application of a temperature of 42 ºC is the optimum temperature for *Bacillus licheniformis ALW1* to produce the enzyme keratinase (figure 3C).

5. Development of feather waste for industry

Processing feather using high pressure steam and chemical processes has required considerable cost and energy. In addition, it can reduce the nutritional value of the product. This process can damage the amino acid components found in feather. The concept of applying biotechnology as an environmentally friendly technology by using microorganisms and their enzymes in feather processing is one of the appropriate solutions [43,44]. The resulting feather waste is very difficult to recycle and is rarely utilized. Waste disposal is a global environmental problem. This waste is responsible for pollution of underground and air water resources [45]. In addition to feather waste, bone waste has also been widely used. One of them is as a raw material for gelatin for industry [46,47]. Keratin protein in hairs causes hair to be resistant to most protease enzymes such as trypsin, pepsin, and papain [37,48]. Based on economic considerations and their impact on the environment, the main focus in waste management is the keratin component. The keratin component can be hydrolyzed through chemical processes [49]. Keratin has been developed into raw material for animal feed, fertilizer and soil moisturizers. [50] The keratin degradation process shows that most pure keratinase cannot dissolve original keratin. This process is a challenge for a number of researchers to uncover further [51]. However, in fact that keratinase which has been produced in nature will regularly destroy large amounts of waste from keratin [52]. Besides bacteria, the use of thermophilic actinomycetes fungi has also been developed to degrade hairy waste. The results showed that as many as twenty thermophilic actinomycetes selected were able to degrade feather waste (87-91%). Increased proteolytic and lipolytic activity and exopolysaccharide production of fungi tested in feathers show a role in the process of degradation of feather components [40]. Actinomycetes are saprophytic bacteria that have the ability to undergo degradation of many complex chemical compounds. This fungus is also capable in the process of mineralization of organic matter and in improving soil structure [53] [54].

6. Conclusion

Feather waste is very rich in keratin protein. Keratin arranges organs in hair, feathers, nails, wool and horns in mammals, reptiles and birds. Keratin is an important type of protein that makes up waste hair. Keratin can be degraded by bacteria and chemical compounds. An important enzyme that plays a role in degrading keratin is keratinase. Keratin has been used extensively in various industries. The use of feather waste is an effort to reduce the environmental burden.

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