Annals of Biology **38** (1) : 118-122, 2022

Impact Score : 0.32 (Scopus)

Valorization of Poultry Feathers into Value Added Products

PRIYANKA BUMBRA*, BABITA KHOSLA AND RISHI KUMAR BEHL[1]

Department of Environmental Sciences, Maharishi Dayanand University, Rohtak-124 001 (Haryana), India
**(e-mail : bumbrapriyanka@gmail.com; Mobile : 97173 79866)*

(Received : October 9, 2021; Accepted : December 10, 2021)

ABSTRACT

Poultry sector is generating huge amount of chicken feather wastes, which fall in the category of keratinous waste : rich in carbon, nitrogen and amino acids. These feathers are recalcitrant in nature and therefore remain in the environment for longer period. However, several microbial communities ranging from bacteria, fungi and actinomycetes were identified to synthesize keratinolytic enzymes possessing the ability to degrade the feathers. These feathers can be modified into potential value-added products like bioactive peptides, animal feed and organic fertilizer.

Key words : Poultry feathers, keratinolytic microorganisms, biodegradation, nitrogenous fertilizer

INTRODUCTION

Chicken meat is considered as one of the cheapest and healthiest sources of protein, resulting in increased annual consumption boosting up the poultry sector. As a result, globally every year around 7 million tonnes of chicken feathers were produced as waste (Verma *et al.*, 2017; da Silva, 2018). Major amount of these feathers is dumped in landfills or burnt as waste or incinerated leading to pollution, while a small proportion is used as feedstock, decorative material, bedding materials, etc. (Tesfaye *et al.*, 2017).

Feathers generally account for an average 5-7% of the total body weight of a mature chicken and are made up of about 91% of keratin protein, 1% lipids and 8% of water (Babalola *et al.*, 2020). The conventional methods used for feather processing include chemical treatment and pressure cooking which convert feathers into animal feed, but these methods not only require huge amount of energy also, destroy amino acids (Kodak *et al.*, 2019). Due to lack of proper management, poultry feather waste has evolved as a major pollutant due to its recalcitrant nature (Brandelli *et al.*, 2015). The recalcitrant property of keratin is result of high order fibrous structures constructed by disulfide bonds, hydrogen bonds and hydrophobic interactions.

Unlike, physical and chemical treatment processes, feather treatments with biological techniques are more optimistic and considered as an alternative environmental-friendly method for recycling and valorizing feathers (Calin *et al.*, 2017; Bhari *et al.*, 2018; Wang *et al.*, 2019), because bioprocesses are favourable in keeping the valuable nutrients that are vulnerable to intolerant conditions of pH, temperature and pressure.

The feather waste is recycled in nature by keratinolytic microorganisms that secrete extracellular keratinases (Tamreihao *et al.,* 2019; Li, 2019). The studies related to biodegradation of feather are more engaged with the screening and determination of various microorganisms that possess the ability to degrade the keratin protein present in feathers. Different microbes including bacteria and fungi have been isolated and identified to have keratinolytic enzyme thus, are able to degrade feathers (Demir *et al.,* 2015; Sivakumar and Raveendran, 2015). Potent keratinase synthesizing microbes have been reported from the bacterial species of genus like *Bacillus, Pseudomonas* and *Streptomyces,* and fungal species belonging to genus *Aspergillus, Penicillium* and *Chrysosporium* (Verma *et al.,* 2017).

This review article presents a discussion on various keratinolytic microorganisms for the management of poultry waste. Since the poultry feather waste is protein-rich waste, prominence is towards the biological conversion of these waste materials into value-added products.

[1]Maharishi Markandeshwar University, Mullana, Ambala-134003 (Haryana), India

Keratin Proteins

Feathers are constructed of keratin protein having molecular weight approx. 10 kDa (Esparza *et al.*, 2017) and extensively cross-linked by disulfide bonding (Lange *et al.*, 2016) which provide rigidity and mechanical stability (Kodak *et al.*, 2019). Keratin protein is rich in amino acids like cysteine, proline and serine, the major proportion is of 8.85% cystine (Table 1). Presence of sulphur in form of thiol (-SH) groups in cysteine leads to the stabilization of the keratin as it forms a network between the adjacent polypeptides through disulphide cross-linkages (Wang *et al.*, 2016). These resolute covalent bonds in conjugation with hydrogen bonding and hydrophobic forces stabilize the three-dimensional structure of protein providing high mechanical strength (Wang *et al.*, 2016).

Table 1. Various amino acids (%) present in keratin fibre of a chicken feather (Sharma and Gupta, 2016)

Functional groups	Amino acid	Per cent content
Positively charged	Arginine	4.30
Negatively charged	Aspartic acid	6.00
	Glutamine	7.62
Hygroscopic	Threonine	4.00
	Serine	16.0
Hydrophobic	Phenylalanine	0.86
	Tyrosine	1.00
	Methionine	1.02
	Valine	1.61
	Leucine	2.62
	Isoleucine	3.32
	Alanine	3.44
	Cystine	8.85
Special	Asparagine	4.00
	Proline	12.0

Keratin proteins are categorized in two types based on structures - α-helix and β-pleated sheet. α keratins are rich in cysteine containing less proportion of proline and hydroxyproline amino acids and generally present in the soft tissues, while β- keratins are aggregated in the hard tissue regions and are enriched with alanine and glycine but lack in cysteine, hydroxyproline and proline amino acids (Sharma and Gupta, 2016).

Valorization of Poultry Feathers

Feathers embrace fat, water and various minerals like nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, zinc and copper, which make them compatible for being served as valuable energy and material sources (Tamreihao *et al.*, 2019) for animals or for microbial growth (Li, 2019).

Microbial degradation of the chicken feathers is the most convenient and environment-friendly method for handling the poultry feather waste so far. Even though feathers of chicken are rich in keratin which makes them resistant to degradation, these are not bulked up in nature, indicating that these are being degraded by certain microbes. Research carried out in past decades shows that there are many micro-organisms that can degrade the keratin rich waste including feathers and the process of microbial degradation of feather is an enzymatic activity. Various strains of bacteria, fungi and actinomycetes secrete extracellular keratinolytic and proteolytic enzymes called keratinases which act upon the keratin protein and degrade the hard protein (Calin *et al.,* 2017; Bohacz and Kowalska, 2019; Li, 2019). Various microbial species like fungi (Table 2) and bacteria including some species of actinomycetes (Table 3) were isolated from different environments capable of producing keratinase enzymes.

Mechanism of Keratin Degradation by Microorganisms

Keratinases are extracellular inducible enzymes produced by microorganisms, which are robust in structure and are specific for keratinous substrates. These enzymes are composed of serine or metalloproteases which possess the ability to degrade both soft and hard keratins by targeting on β-pleated sheets and

Table 2. Various fungal species known to produce the keratin enzyme

Fungi	Source	References
Aspergillus niger, A. fumigatus, A. parasiticus and *A. flavus*	Feather, poultry soil	Sivakumar and Raveendran (2015)
Fusarium solani	Soil	Ca^lin *et al.* (2017)
Penicillium purpurogenum	Tannery soil	Nwadiaro *et al.* (2015)
Microsporum gypseum	Feathers	Li (2019)
Onygena corvina	Feathers, hooves, horn	Lange *et al.* (2016)

Table 3. Various bacteria species known to produce the keratin enzyme

Bacteria	Source	References
Bacillus licheniformis, B. subtilis, B. pumilis, B. pseudofirmus, B. cereus, B. thuringiensis	Wild bird, poultry farm soil	Fellahi *et al.* (2016), Hashem *et al.* (2018), Wang *et al.* (2019), Yadav and Khosla (2021)
Paenibacillus woosongensis	Soil	Li (2019)
Pseudomonas fluorescens, P. stutzeri, P. fulva	Agricultural land, Wild bird	Chaturvedi *et al.* (2014)
Stenostrophomonas maltophilia	Soil of reed	Herzog *et al.* (2016)
Chryseobacterium sp.	Poultry waste	Hong *et.al.* (2015)

α-helical structures (Verma *et al.*, 2016; Bhari *et al.*, 2019). *In vitro* studies of the keratinase structure and feather degradation have led researchers to a conclusion that the keratin degradation is not achieved by a single keratinase enzyme as they lack the ability to break the disulphide bonds present in keratin (Li, 2019). After several proposed mechanisms, it has been recognized that keratinolytic process is mainly comprised of two different processes : sulphite-o-lysis -process of breaking disulphide bonds and proteolysis, process of protein breakdown which is followed by the process of deamination (Tamreihao *et al.*, 2019). Enzymes like sulphide reductases or some reducing agents such as sulphite are emanated by the microbe which plays the crucial part in removing the disulphide bonds associated in keratin, ultimately changing the structural conformations, and availing more active sites for further action by proteolytic enzymes (Lange *et al.*, 2016). Finally, the feathers were efficiently degraded to peptides and soluble amino acids (Fig. 1).

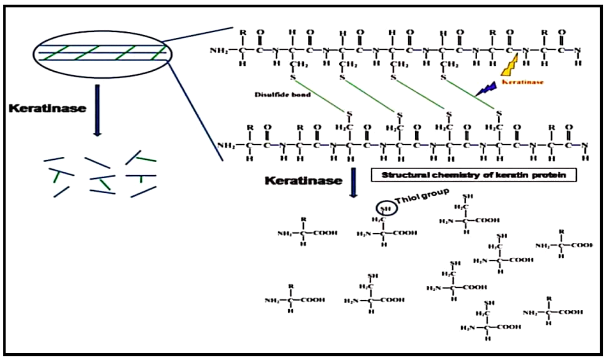

Fig. 1. Mechanism of action of keratinolytic enzymes with schematic representation of keratin protein (Hashem *et al.*, 2018).

Bacteria and fungi follow different mechanisms for the purpose of keratin degradation. In addition to the above cited processes viz., sulphite-o-lysis and proteolysis, mechanical destruction of the keratin also plays a vital role in degradation by fungi (Li, 2019).

Feather Conversion to Fertilizer

The potential of microbial keratinases to enhance and accelerate the composting of dead chicken or discarded feathers could be a feasible and eco-friendly technique of recycling these organic wastes into nitrogen-rich fertilizers (Brandelli *et al.*, 2015). The hydrolysates obtained after the microbial treatment of poultry feathers could be used as organic nitrogen fertilizer/soil conditioner (Brandelli *et al.*, 2015) as it is rich in soluble proteins, amino acids, enzymes and many other valuable products (Pahua-Ramos *et al.*, 2017). Microbial action on feathers causes a slow release of nitrogen which is readily available to plants (Kumar, 2021). Also, the degradation of keratin leads to release of tryptophan in large amount which is a key source for the synthesis of indole-3- acetic acid by microbes, thus providing a plant growth promoting activity (Bhange *et al.*, 2016). Feather compost increases the N, P and K content of the soil leading to surplus growth of the crops.

In a study on rapeseed, the microbe derived feather hydrolysate significantly increased plant biomass (Popko *et al.*, 2015). Further, the metabolites produced after feather degradation positively affect the germination and growth of plants (Bhange *et al.*, 2016) as well as enhance the chemical properties of the soil like increase in the water holding capacity and permeability of the soil (Nagarajan *et al.*, 2017).

Feathers Conversion to Animal Feed

The traditional methods of handling feather waste include burning in open, incineration, land filling and degradation by physical (steam cooking) chemical methods (Acid/alkali hydrolysis). Since keratins protein embraced in feathers is rich source of essential amino acids like cysteine, glutamine, proline and serine amino acids (Tesfaye *et al.*, 2017), feathers are used for production of animal feeds by steam and chemical treatment (Sharma and Gupta, 2016). In place of alkali hydrolysis and steam pressure-cooking of feathers, feather degradation via keratinase seems to be a viable alternative providing resultant products with better nutritional properties for being used as animal feed (Brandelli *et al.,* 2015). There have been number of keratinolytic proteases investigated for meeting the purpose of producing hydrolysed feather keratin for feed production. *Bacillus licheniformis* is reported to produce keratinase that enhanced the digestibility of the total amino acid from 30 to 66% of raw feather and from 77 to 99% commercial feather meal. Also, the commercial product Versazyme®, is derived from keratinase identical to subtilisin produced by *B. licheniformis*, effectively examined as feed additive (Brandelli *et al.*, 2015).

Moreover, studies have revealed that chicken feather hydrolysates produced by use of microbial keratinase result in improved nutritional values, protein efficiency ratio and protein digestibility than the feather keratin and feather meal (Kumar, 2021). In a comparative study among the enzymatic and alkali treatments for processing feathers from dead hens suggested that the separation of feathers was faster with alkaline treatment while the nutritional characteristics of feathers were improved by feather-digesting enzyme (Brandelli *et al.*, 2015).

The amino acids content of chicken feathers degraded by keratinases from *Microsporum fulvum* IBRL SD3 comprised various essential amino acids viz., threonine, valine, methionine, isoleucine, leucine, lysine, histidine and tyrosine (Kshetri *et al.*, 2017). Hence, it demonstrates that hydrolysed feather protein can be a significant source of protein that may be used in animal diets. The molecular weights of the polypeptides in the hydrolysate were found to be approximately 1.3 kDa. This indicates that the hydrolysate was mainly composed of short peptides/ oligopeptides, which are easily absorbed by animals and have potential applications in food additives (Peng *et al.*, 2019).

CONCLUSION

The poultry feathers which are worldwide adding on the loads of waste can be utilized as a valuable resource by the use of keratinase producing microbes, instead of dumping into the landfills or treating them with high cost chemical and physical method for further use. The feather hydrolysate thus produced is enriched in minerals and essential amino acids like tryptophan, which act as the precursor for indole acetic acid promoting the root growth in plant. In addition to the plant growth and regulation, the hydrolysed keratinous material helps in nourishing the soil and improving its quality.

REFERENCES

Babalola, R., Ayeni, A. O., Joshua, P. S., Ayoola, A. A., Isaac, U. O., Aniediong, U., Efeovbokjhan, V. E. and Omoleye, J. A. (2020). Synthesis of thermal insulator using chicken feather fibre in starch-clay nanocomposites. *Heliyon* **6** : e05384. *doi : org/10.1016/j.heliyon.2020.e05384.*

Bhange, K., Chaturvedi, V. and Bhatt, R. (2016). Ameliorating effects of chicken feathers in plant growth promotion activity by a keratinolytic strain of *Bacillus subtilis* PF1. *Bioresources and Bioprocessing* **3** : 3-13.

Bhari, R., Kaur, M. and Singh, R. S. (2019). Thermostable and halo tolerant keratinase from *Bacillus aerius* NSMk2 with remarkable dehairing and laundry applications. *J. Basic Microbiol.* **59** : 555-568.

Bhari, R., Kaur, M., Singh, R. S., Pandey, A. and Larroche, C. (2018). Bioconversion of chicken feathers by *Bacillus aerius* NSMk2 : A potential approach in poultry waste management. *Bioresource Technology Reports* **3** : 224-230.

Bohacz, J. and Kornillowicz-Kowalska, T. (2019). Fungal diversity and keratinolytic activity of fungi from lignocellulosic composts with chicken feathers. *Process Biochem.* **80** : 119-128.

Brandelli, A., Sala, L. and Kalil, S. J. (2015). Microbial enzymes for bioconversion of poultry waste into added-value products. *Food Res. Int.* **73** : 3-12.

Calin, M., Constantinescu-Aruxandei, D., Alexandrescu, E., Raut, I., Doni, M. B., Arsene, M. L., Oancea, F., Jecu, L. and Lazar, V. (2017). Degradation of keratin substrates by keratinolytic fungi. *Electronic J. Biotechnology* **28** : 101-112.

Chaturvedi, V., Bhange, K., Bhatt, R. and Verma, P. (2014). Production of kertinases using chicken feathers as substrate by a novel multifunctional strain of *Pseudomonas stutzeri* and its dehairing application. *Bio-catalysis and Agric. Biotechnol.* **3** : 167-174.

da Silva, R. R. (2018). Keratinases as an alternative method designed to solve keratin disposal on the environment : Its relevance on agricultural and environmental chemistry. *J. Agric. Food Chem.* **66** : 7219-7221.

Demir, T., Hames, E. E., Oncel, S. S. and Vardar, S. F. (2015). An optimization approach to scale up keratinase production by *Streptomyces* sp. 2M21 by utilizing chicken feather. *Int. Biodeterioration Biodegradation* **103** : 134-140.

Esparza, Y., Ullah, A. and Wu, J. (2017). Preparation and characterization of graphite oxide nano-reinforced biocomposites from chicken feather keratin. *J. Chem. Tech. Biotechnol.* **92** : 2023-2031.

Fellahi, S., Chibani, A., Lagerstedt, E. F. and Taherzadeh, M. J. (2016). Identification of two new keratinolytic proteases from a *Bacillus pumilus* strain using protein analysis and gene sequencing. *AMB Express* **6** : 42. *doi: 10.1186/s13568-016-0213-0.*

Hashem, A. M., Abdel-Fattah, A. M., Ismail, S. A., El-Gamal, M. S., Esawy, M. A. and Emran, M. A. (2018). Optimization, characterization and thermodynamic studies on *B. licheniformis* ALW1 keratinase. *Egyptian J. Chem.* **61** : 591-607.

Herzog, B., Overy, D. P., Haltli, B. and Kerr, R. G. (2016). Discovery of keratinases using bacteria isolated from marine environments. *Syst. Appl. Microbiol.* **39** : 49-57.

Hong, S. J., Park, G. S., Jung, B. K., Khan, A. R., Park, Y. J. and Lee, C. H. (2015). Isolation, identification and characterization of a keratin-degrading bacterium *Chryseobacterium* sp. P1-3. *J. App. Biol. Chem.* **58** : 247-251.

Kodak, S., Gharge, T., Chavan V. and Sibi, G. (2019). Microbial degradation of poultry feather wastes under the influence of temperature and pH–A review. *Int. J. Environ. Sci. Natural Res.* **21** : 556063. *doi : 10.19080/ijesnr.2019.21.556063.*

Kshetri, P., Roy, S. S., Sharma, S. K, Singh, T. S., Ansari, M. A., Prakash, N. and Ngachan, S. V. (2017). Transforming chicken feather waste into feather protein hydrolysate using a newly isolated multifaceted keratinolytic bacterium, *Chryseobacterium sediminis* RCM-SSR-7. *Waste and Biomass Valorization* **10** : 1-11.

Kumar, J. (2021). Microbial hydrolyzed feather protein as a source of amino acids and protein in the diets of animals including poultry. *Adv. Poultry Nutrition Res. doi : 10.5772/intechopen.96925.*

Lange, L., Huang, Y. and Busk, P. K. (2016). Microbial decomposition of keratin in nature–a new hypothesis of industrial relevance. *App. Microbiol. Biotechnol.* **100** : 2083-2096.

Li, Q. (2019). Progress in microbial degradation of feather waste. *Frontiers in Microbiology* **10** : 2717. *doi: 10.3389/fmicb.2019.02717.*

Nagarajan, S., Eswaran, P., Masilamani, R. P. and Natarajan, H. (2017). Chicken feather compost to promote the plant growth activity by using keratinolytic bacteria. *Waste and Biomass Valorization* **9** : 531-538.

Nwadiaro, P. O., Chuku, A., Onyimba, I. A., Ogbonna, A. I., Nwaukwu, I. A. and Adekojo, D. A. (2015). Keratin degradation by *Penicillium purpurogenum* isolated from tannery soils in Jos, Nigeria. *Microbiol. Res. J. Int.* **8** : 358-366.

Pahua-Ramos, M. E., Hernández-Melchor, D. J., Camacho-Pérez, B. and Quezada-Cruz, M. (2017). Degradation of chicken feathers : A review. *Biotechn. An Ind. J.* **13** : 153.

Peng, Z., Mao, X., Zhang, J., Du, G. and Chen, J. (2019). Effective biodegradation of chicken feather waste by co-cultivation of keratinase producing strains. *Microbial Cell Factories* **18** : 84. *doi : org/10.1186/s12934-019-1134-9.*

Popko, M., Wilk, R., Gorecka, H., Chojnacka, K. and Gorecki, H. (2015). Assessment of new NKS Mg fertilizer based on protein hydrolysate of keratin in pot experiments. *Polish J. Environ. Studies* **24** : 1765-1772.

Sharma, S. and Gupta, A. (2016). Sustainable management of keratin waste biomass : Applications and future perspectives. *Brazilian Archives of Biol. and Technol.* **59** : 1-4.

Sivakumar, N. and Raveendran, S. (2015). Keratin degradation by bacteria and fungi isolated from poultry farm and plumage. *British Poultry Sci.* **56** : 210-217.

Tamreihao, K., Mukherjee, S., Khunjamayum, R., Devi, L. J., Asem, R. S. and Ningthoujam, D. S. (2019). Feather degradation by keratinolytic bacteria and biofertilizing potential for sustainable agricultural production. *J. Basic Microbiol.* **59** : 4-13.

Tesfaye, T., Sithole, B. and Ramjugernath, D. (2017). Valorization of chicken feathers : A review on recycling and recovery route : Current status and future prospects. *Clean Tech. Environ. Policy* **19** : 2363-2378.

Verma, A., Singh, H., Anwar, S., Chattopadhyay, A., Tiwari, K. K., Kaur, S. and Dhillon, G. (2017). Microbial keratinases : Industrial enzymes with waste management potential. *Critical Rev. Biotech.* **37** : 476-491.

Wang, B., Yang, W., McKittrick, J. and Meyers, M. A. (2016) Keratin : Structure, mechanical properties, occurrence in biological organisms and efforts at bioinspiration. *Progress in Material Sci.* **76** : 229-318.

Wang, T., Liang, C., Sun, Y., Gao, W., Luo, X., Gao, Q., Li, R., Fu, S., Xu, H., He, T. and Yuan, H. (2019). Strategical isolation of efficient chicken feather-degrading bacterial strains from tea plantation soil sample. *Int. Microbiol.* **22** : 227-237.

Yadav, S. and Khosla, B. (2021) Biodegradation of poultry feather waste by keratinase producing *Bacillus cereus* strain isolated from poultry farms waste disposal site. *Case Studies in Chemical and Environmental Engineering* **4.** *doi.org/10.1016/j.cscee. 2021.100114.*