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Microbial Hydrolysed Feather Protein as a Source of Amino Acids and Protein in the Diets of Animals Including Poultry

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Abstract

Feathers are hard waste products, mainly composed of hard β -keratin, and are produced in large quantities in commercial poultry processing plants. Therefore, their industrial utilization is important economically as well as environmentally. Feathers degradation through keratinolytic microorganisms has been considered as an important method for efficient bioconversion, nutritional enhancement and eco-friendliness. The use of crude keratinase significantly increased the amino acid digestibility of raw feathers and commercial feather meal. This enzyme increased the digestibility of commercial feather meal and could replace as much as 7% of the dietary protein for growing chicks. However, feathers are currently utilized on a limited basis as a dietary protein supplement for animal feed because feather meal production is an expensive process, requiring significant amounts of energy. This review paper explains the nutritive value of feathers which makes suitable and inexpensive animal and poultry feed.

Keywords: feather, feather meal, keratin, animal feed, keratinase, protein hydrolysate

1. Introduction

Rising livestock is a major industry, which produces animals that have multiple uses as meat, fibers and hides. It is important to feed the stock animals a proper balanced diet, to insure optimum growth and health. Feed Industries are seeking new way to cope with raw materials costs [1]. Viable treated feather and hog hair meals have been found valuable sources of dietary protein for the growing chick [2]. Recently, supplementation of poultry diets with enzyme mixtures, including protease and amylase has produced improvements in growth performance [3]. Keratinase is an enzyme hydrolyses a broad range of protein substrate including casein, collagen, elastin and keratin [4]. Scientist reported degradation of chicken feathers and other keratinous waste materials by fungi [5] and decomposed

feathers were utilized as nitrogenous fertilizers due to their high value protein content [6, 7]. This feature of keratin protein can accomplish the shortage of meat raw materials and achieve desire of manufacturer to reduce production costs, and the availability of alternative sources of protein [8]. Feather degradation by microbial action seems to be a reasonable substitute to obtain feather meal that would be nutritionally raised with essential amino-acids. This line of biodegradation of chicken feathers would convert the rigid feather waste to a readily digestible feather meal.

2. Keratin

Keratin is hardened fiber plus matrix material which ultimately fills the cells of hair cortex. It thus consists of two main components; a fibrous protein which gives the α -keratin x-ray diffraction pattern (or the β -pattern when the polypeptide chains are extended as in feather keratin) and an amorphous protein which is termed γ -keratin [9]. Only rare microorganisms like fungi, bacteria and actinomycetes are capable to break and utilize keratin because of their hard and tough nature. Humans and other vertebrates cannot digest this macromolecule, and if eaten, it simply gets accumulated within the variety of a lump that is still undigested. A large part of tiger scat and other carnivore dung contains scleroprotein (mainly hair) aside from bones and additional complex elements which are undigestible [10]. Animal hair, hoofs, horns and wool contain β -keratin and bird's feather contains α -keratin. Keratins are also present in epithelial covering which is rich in beta helical coil linked through cysteine bridges [11]. The higher the percentage of sulfur, the higher is the stability of keratin towards solubilization [12]. The keratin proteins are compound that are extremely resistant to action of physical, chemical and biological agents. Hair, horns, nails and cornified tissue are some naturally occurring forms of keratin [13–14]. Keratin is a protein macromolecule with very high stability and low degradation rate.

Keratins are categorized into hard and soft keratins according to the sulfur content. Hard keratins have high content di-sulphide linking and are found in appendages. Soft keratins have low content of disulphide bond making skin and callus [15]. Keratins belong to the super family of IF protein. Intermediate filament proteins are planned, prolonged α -helical conformation prone to form two-stranded coiled coils. The durability of keratins is a direct consequence of their complex architecture [16].

2.1 Chicken feathers

The main component of feather is keratin, a mechanically durable and chemically unreactive and insoluble protein, which render it difficult to be digested by most proteolytic enzymes. Keratin is resistant to enzymatic digestion by plant, animals and many known microbial proteases due to insoluble nature. Feathers having only 10% parts which is not keratin, rest 90% is resistant to degradation by common peptidases. This resistance is due to constituent amino acid composition and configuration that provide structural rigidity [17]. Chicken feathers are made up of over 90% of keratin protein, small amounts of lipids and water. Feathers contain about 15% N on a dry weight basis and huge quantities are produced as industrial by product. However, they have not been used effectively as plant bio

fertilizers since N mineralization are slow meet plant requirements [18]. Feather waste, resulting in large quantities as by product of poultry farms processing, are pure keratin proteins.

3. Keratinases from microorganism

The keratinase producing micro-organisms have been discovered in several different biological groups, including fungi, bacteria and actinomycetes.

3.1 Bacterial strains

The genera *Burkholderia*, *Chryseobacterium*, *Pseudomonas* and *Microbacterium* sp. were grown on solid medium with feather meal as sole carbon and chemical elements and screened for proteolytic activity on milk agar plates [19]. Three *Bacillus* species were isolated from the poultry industry and evaluated for keratinase production using feathers or feather meal as the sole carbon and nitrogen sources in a submerged fermentation. *B. subtilis* 1273 was the strain which exhibited the highest enzymatic activity [17]. A number of keratinases producing *Bacillus* and *Pseudomonas* species have been isolated from various environmental sources such as soil farm wastes and raw feather [20]. *Bacillus* sp., *Bacillus licheniformis*, *Bacillus subtilis* KD-N2, *Burkholderia* was isolated for keratinase production [21–22].

3.2 Actinomycetes strains

Thiosulfate production from cystine by keratinolytic prokaryote *Streptomyces fradiae* [23]. Biochemical mechanism of keratin degradation by the actinomycete *Streptomyces fradiae* and the fungus *Microsporium gypseum*: a comparison [24]. Keratinolytic serine protease was purified and characterized from *Streptomyces albidoflavus* [25]. Native keratin decomposition by thermophilic *Actinomycetes* was studied [26]. Keratinase enzyme was isolated and characterized, which was produced during wool degradation process by *Thermoactinomyces candidus* [27]. *Thermoactinomyces* degraded keratin and other collagenous waste by alkaline hydrolysis [28]. A new strain of *streptomyces* was used to degrade feather [29]. A new actinomycetes was isolated from coastal region of south India and studied keratinase production [30].

3.3 Fungal strains

The thermophiles may be advantageous in comparison with mesophiles, because of their accelerated reaction processes and the accumulation of biomass and enzymes and diminished the risk of contamination in industrial activity. A large number of keratinases producing fungi were observed by [31]. 234 fungal strains were isolated by baiting method used for feather degradation and keratinase producing ability. Maximum clearing zone was made by *Chrysosporium indicum* on solid agar plates. The highest keratinase production was found in case of *Acremonium strictum* while *Chrysosporium indicum* and *Chrysosporium tropicum* was found next to it [32]. Fungal keratinase reported from India are listed in Table 1.

| Fungal species | Aim of study | Author | References |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------|---------------------|------------|
| <i>Acrodontium album</i> , <i>Aspergillus ustus</i> , <i>A. quercinus</i> , <i>otryotrichum keratinophilum</i> , <i>Chaetomium globosum</i> , <i>Chrysosporium crassitunicatum</i> , <i>C. tropicum</i> , <i>Curvularia indica</i> , <i>Gliocladium agrawalii</i> , <i>G. roseum</i> , | Keratinase activity | Kushwaha | [33] |
| <i>Geotrichum candidum</i> | Keratinase | Rajak et al. | [34] |
| <i>Trichophyton simii</i> | Characterization | Singh | [35] |
| <i>C. tropicum</i> , <i>C. keratinophilum</i> , <i>C. pannorum</i> , <i>C. queenslandicum</i> , <i>Malbranchea flava</i> , | Keratinase | Kaul and Sumbali | [36] |
| <i>C. keratinophilum</i> , <i>C. queenslandicum</i> , <i>C. tropicum</i> , <i>C. indicum</i> , <i>Malbranchea chrysosporoidea</i> , <i>Scopulariopsis brevicaulis</i> , <i>Curvularia lunata</i> | Keratinase production | Kaul and Sumbali | [37] |
| <i>Scopulariopsis brevicaulis</i> | Dehairing process | Anbu et al. | [38] |
| <i>Microsporum gypseum</i> | Secretion of keratinase | Raju et al. | [39] |
| <i>Acremonium strictum</i> | Optimization of media composition | Kumar and Kushwaha | [40] |
| <i>Cunninghamella echinulata</i> | Purification & Characterization | More et al. | [41] |
| <i>Aspergillus fumigatus</i> | Purification of keratinase | Paul et al. | [42] |
| <i>Acremonium strictum</i> , <i>C. indicum</i> , <i>C. tropicum</i> , <i>C. queenslandicum</i> , <i>C. pannicola</i> , | Screening for keratinase | Kumar and Kushwaha | [32] |
| <i>Aspergillus flavus</i> | Optimization in SSF Condition | Mini et al. | [43] |
| <i>Scopulariopsis brevicaulis</i> | Statistical optimization | Satyalakshmi et al. | [44] |

Table 1.
Fungal species producing keratinase.

4. Feathers as source of proteins and amino acids

An appealing alternating method to obtain amino acids and proteins is to use feathers that are relatively stable under natural conditions. Keratinophilic fungi used to hydrolyse keratin protein to obtain protein [33] and found maximum producer as *C. indicum*, *C. tropicum*, and *Malbranchea pulchella*. Parihar and Kushwaha [45] used *Verticillium tenuipes*, *Microsporum gypseum*, *Aphanoascus fulvescens*, *Chrysosporium keratinophilum* for study of protein release in hen feather degradation without rachis. *C. indicum* was used for degradation of human hair and estimated protein release 47.66 µg/ml and 112.66 µg/ml in 5 and 10 days respectively [46]. *Chrysosporium tropicum*, *Penicillium griseofulvum* and *Aphanoascus terreus* was analyzed for release of considerable amount of protein [47]. [48] observed protein release 409.6 µg/ml in case of *C. tropicum* in 12 days while *Malbranchea* sp. released 298.21 µg/ml in 4 days. [46] recorded 238 µg/ml in 25 days by *Alternaria tenuissima*. Conversion of feathers into feather meals by applying physical and chemical methods results in the loss of nutritionally essential amino acids such as methionine, lysine and tryptophan. Therefore, currently the poultry feathers are converted into feather meal, a digestible dietary protein, for animal feed using keratinases. The microbial production of L-lysine is an expanding branch of manufacturing biotechnology. There are many reports are available worldwide. Indian researcher [37] studied the discharge of cysteine in the culture medium.

[47] recorded cysteine produced by *Acremonium strictum* 32.00 µg/mL, *Chrysosporium tropicum* 25.00 µg/mL, *Chrysosporium indicum* 22.00 µg/mL, *Malbranchea aurantiaca* 21.00 µg/mL. [48] Studied the discharge of amino acids lysine, cysteine, methionine, valine by *C. tropicum* and *Malbranchea* sp. due to feather degradation. [6] Found *A. tenuissima* a potent feather degrading fungus and increased the nourishing value of the soil by adding proteins (238 µg/ml), cysteine (20.2 µg/ml), lysine (15.8 µg/ml), methionine (6.8 µg/ml) and valine (7.5 µg/ml) in 25 days.

4.1 Animal feed

The upgradation of feather meal through microbial or catalyst treatment has been defined earlier. Feather meal fermented with *Streptomyces fradiae* and supplemented with essential amino acid methionine bring about in the broilers growth rate comparable with those fed isolated soybean protein [49]. The application of feather-lysate from *B. licheniformis* with amino acid supplementation formed alike development rate in chickens when compared to chickens fed with a diet included with soybean meal [50]. Feather hydrolysates produced by microbial keratinases have been used as additives for animal feed [51]. The application of biotechnological approach using microbes for feather processing has nutritional significance. Culturing of the microorganisms and keratinase activity may result in modification of structure of feather keratin [4, 52–54]. This may alter its resistance to digestive enzymes of the consuming animals [55]. Fermentation of feathers involving microorganisms and microbial enzymes, not only it would retain the existing valuable amino acid content of keratin, but it would also add to it. Thus, the feather meal obtained after such microbial treatment would have enough nutritional value. Keratinase could play a significant role in enzymatic improvement of feather meal and amino acid production from high molecular weight substrate [56]. The microbial technology would significantly bring down the cost since it would not require hydrothermal treatment, however feather waste would be a cheap raw material [57].

4.2 Feather meal as Chick feed

Meat and feather meal protein gave equally as good results as soybean meal protein when supplied 3% protein in practical-type corn-soybean meal rations [58]. [59] observed growth of feather and composition in broiler chicken and found that that of threonine, isoleucine and valine increased with age while methionine content of feathers decreased with age. *B. licheniformis* produced crude keratinase enzyme augmented the total amino acid digestibility of raw feathers and commercial feather meal, could replace as much as 7% of the dietary protein for growing chicks [19]. [60] Studied dietary crude protein and lysine amino acid effect on growth of feather in chicks and found that crude protein has more influence on feather development than by levels of lysine. [61] Observed antioxidant potential property of protein hydrolysate developed by *Bacillus* sp. [62] observed replacement of fish meal with feather meal in broiler and found economic without any negative effect. Treated chicken feather meal used as a source of protein in animal feed broiler chickens [63]. [64] Observed processed feather meal for their chemical composition and amino acid profile and found feather meal pre-soaked with wood ash for twenty-four hours boiled at 150°C for 1 hr. gave the best crude protein content. Using feather waste as a valuable resource can help the poultry industry to dispose of the waste feathers in an environmentally sustainable manner that also generates extra income for the industry [65]. [66] Improved digestibility of protein into feather meal by

enzymatic treatment. Feather meal can be included in the broilers diet without any negative effect on its performance [67]. [68] Studied effect of hydrolysed feather meal on feed efficiency, survival rate and carcass composition of red tilapia.

5. Conclusion

Microbial keratinase substances improve keratin protein hydrolysis and increases nutritive value of feather meal. Microbial hydrolysed protein is rich in essential amino acid contents and other oligopeptides which are good and cheap for poultry feed. Supplementary learning outcome is desirable in an integrated sustainable approach to solve environmental issue of keratinous solid waste management and provide cheap and healthy feed.

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References

- [1] Pederson MB, Yu S, Plumstead P, Dalsgaard S. Comparison of four protease for improvement of nutritive value of poultry feather meal. J Animal Science. 2012; Doi:10.2527/jas.53795
- [2] Moran ET Jr, J. D. Summers JD, Slinger SJ. Keratins as sources of protein for the growing chick. 1. Amino acid imbalance as the cause for inferior performance of feather meal and the implication of disulfide bonding in raw feathers as the reason for poor digestibility. Poultry Sci. 1966; 45: 1257-1266.
- [3] Greenwood MW, Fritts CA and Waldroup. Utilization of avizyme 1502 in corn-soyabean meal diets with and without antibiotics. Poultry Science. 2002; 81(suppl 1):25.
- [4] Odetallah NH, Wang JJ, Garlich JD, Shih JCH. Keratinase in starter diets improves growth of broiler chicks. Poultry Science. 2003; 82:664-670.
- [5] Kumar J, Yadav R. Keratinolysis of human hair and chicken feather by nondermatophytic keratinophilic fungi isolated from soil. Journal of Applied and Natural Science. 2020; 12(4):568-574.
- [6] Kumari M, Kumar J. Chicken feather waste degradation by *Alternaria tenuissima* and its application on plant growth. Journal of Applied and Natural Sciences. 2020; 12(3): 411-414. <https://doi.org/10.31018/jans.v12i3.2345>.
- [7] Kumar J, Kumar P, Kushwaha RKS. Recycling of chicken feather protein into compost by *Chrysosporium indicum* JK14 and their effect on the growth promotion of *Zea mays*. Plant Cell Biotechnology and Molecular Biology. 2020;21(37&38): 75-80.
- [8] Volik V, Ismailova D, Lukashenko V, Saleeva I, Morozov V. Biologically active feed additive development based on keratin and collagen- containing raw materials from poultry waste. International Transaction Journal of engineering management & Applied Science & Technologies. 2020; 11 (5): 1-10.
- [9] Mathison GE. The microbiological decomposition of keratin. Ann. Soc. Belge Med. Trop. 1964; 44: 767-792.
- [10] Sharma R, Rajak RC. Keratinophilic fungi: Nature's keratin degrading machines! Their isolation, identification and ecological role. Resonance. 2003:28-40
- [11] Vigneshwaran C, Shanmugam S, Sathish Kumar T. Screening and characterization of keratinase from *Bacillus licheniformis* isolated from Namakkal poultry farm. Researcher. 2010; 2(4):89-96.
- [12] Maruthi Y Avasn, Lakshmi K Aruna, Rao S Ramakrishna, Chaitanya D Apta. *Chrysosporium tropicum* A potential feather/hair waste degrading keratinophilic fungi E3. journal of environmental research and management. 2011; 2(1):014-018.
- [13] Kainoor Pushpalata S, Naik GR. Production and characterization of feather degrading keratinase from *Bacillus* sp. JB 99. Indian journal of Biotechnology. 2010 9:384-390.
- [14] Duarte TR, Oliveria SS, Macrae A, Cedrola SML, Mazotto AM, Souza EP, Melo CAN, Vermelho AB. Increased expression of keratinase and other peptidases by *Candida parapsilosis* mutants. Brazilian Journal of medical and biological research. 2011; 44 (3): 212-216.
- [15] Selvam K. Biochemical and molecular characterization of microbial keratinase and its remarkable

applications. International journal of pharmaceutical and biological archives. 2012; 3(2): 267-275.

[16] Inamdar Areeb, Nasreen Sahera, Siddiqui Rashiqua. Screening and production of extracellular feather degrading enzyme from bacterial isolates. Indian journal of life Sciences. 2012;1(2): 19-24.

[17] Mazotto AM, Rodrigues CRR, Cedrola SML, Fábio de Lima M, Couri Sonia, De Souza EP, Vermelho AB. Keratinase production by three *Bacillus* sp. using feather meal and whole feather as substrate in a submerged fermentation. Enzyme research. 2011; 523780, 7 doi:10.4061/2011/523780

[18] Choi JM, Nelson PV. Developing a slow- release nitrogen fertilizer from organic sources, I using nonviable bacteria. J. Amer. Soc. Hort. Sci. 1996; 121, 629-633.

[19] Riffel A, Brandelli A. Keratinolytic bacteria isolated from feather waste. Brazilian journal of microbiology. 2006; 37: 395-399.

[20] Okoroma Emeka A, Hemda Garelick, Abiola Oduola O, Purchase Diane. Identification and characterization of a *Bacillus licheniformis* strain with profound keratinase activity for degradation of melanised feather. 2012

[21] Gupta R, Ramnani P. Microbial keratinases and their respective applications: An Overview. Applied Microbiol. Biotechnol. 2006; 70: 21-33.

[22] Sangali S, Brandell, A. Isolation and characterization of a novel feather degrading bacterial strain. Applied biochemistry and Biotechnology. 2000; 87, 17-24.

[23] Kunert, J. & Stransky, Z. Thiosulfate production from cystine by keratinolytic prokaryote *Streptomyces*

fradiae. Archives of Microbiology. 1988; 150: 600-601.

[24] Kunert, J. 1989 Biochemical mechanism of keratin degradation by the actinomycete *Streptomyces fradiae* and the fungus *Microsporum gypseum*: a comparison. Journal of Basic Microbiology. 1989; 29: 597-604.

[25] Bressollier P, Letourneau F, Urdaci M, Verneuil B. Purification and characterization of a keratinolytic serine protease from *Streptomyces albidoflavus*. Applied and Environ Microbiol. 1999; 65, 2570-2576.

[26] Ignatova Z, Gousterova A, Spassov G, Nedkov P. Decomposition of native keratin by thermophilic actinomycetes. Comptes Rendus de l'Academie Bulgare des Sciences 1998;51: 67-70.

[27] Ignatova Z, Gousterova A, Spassov G, Nedkov P. 1999 Isolation and partial characterization of extracellular keratinase from a wool degrading thermophilic actinomycete strain *Thermoactinomyces candidus*. Canadian Journal of Microbiology. 1999; 45: 217-222.

[28] Gousterova A, Braikova D, Goshev I, Christov P, Tishinow K, Vasileva-Tonkova E, Haertle T, Nedkov P. Degradation of keratin and Collagen containing wasted by newly isolated thermoactinomycetes by alkaline hydrolysis, Letters appl. Microbiol. 2005; 40:335-340.

[29] Mona EM. Feather degradation by a new keratinolytic *Streptomyces* sp MS-2. World. J. Microbiol. Biotechnol. 2008; 24:2331-2338.

[30] Selvam K, Vishnupriya B, Yamuna Isolation M. and description of keratinase producing marine actinobacteria from South Indian Coastal Region. African Journal of Biotechnology. 2013; 12(1): 19-26.

- [31] Gradisar H, Kern S, Friedrich J. Keratinase of *Doratomyces microsporus*. Appl. Microbiol. Biotechnol. 2000; 53:196-200.
- [32] Kumar J, Kushwaha RKS. Screening of fungi efficient in feather degradation and keratinase production. Arch. Appl. Sci. Res.2014; 6(1): 73-78.
- [33] Kushwaha RKS. The *in vitro* degradation of peacock feathers by some fungi. Mycosen.1983; 26:324-326.
- [34] Rajak RC, Parvekar S, Malviya H, Hasija SK. Keratin degradation by fungi isolated from grounds of a gelatine factory on Jabalpur, India. Mycopathologia. 1991; 114: 83-87.
- [35] Singh CJ. Characterization of an extracellular keratinase of *Trichophyton simii* and its role in keratin degradation. Mycopathologia. 1997; 137:13-16.
- [36] Kaul S, Sumbali G. Keratinolysis by poultry farm soil fungi. Mycopathologia. 1997; 139 (3): 137-140.
- [37] Kaul S, Sumbali G. Production of extracellular keratinase by keratinophilic fungal species inhabiting feathers of living poultry birds (*Gallus domesticus*): A comparison. Mycopathologia.1999; 146: 19-24.
- [38] Anbu P, Gopinath SCB, Hilda A, Lakshmipriya T, and Annadurai G. Purification of keratinase from poultry farm isolate *Scopulariopsis brevicaulis* and statistical optimization of enzyme activity. Enzyme and Microbial Technology. 2005; 36(5-6):639-647.
- [39] Raju KC, Neogi U, Saumya R, Goud NR. Studies on extra cellular enzyme keratinase from dermatophyte *Microsporum gypseum*. International J of Biological Chemistry. 2007; 1(3): 174-178.
- [40] Kumar J, Kushwaha RKS. Optimization of media composition for keratinase production on feather by *Acremonium strictum* RKS1. Advances in Applied Science Research.2012; 3(5):3233-3243.
- [41] More SS, Sridhar DL, Prakash SN, Vishwakarma J & Umashankar S. Purification and properties of novel fungal alkaline keratinase from *Cunninghamella echinulata*. Turkish J. of Biochem. 2013; 38(1): 68-74.
- [42] Paul T, Das A, Mandal A, Halder SK, Mohapatra PKD, Pati BR and Mondal KC. Production and purification of keratinase using chicken feather bioconversion by a newly isolated *Aspergillus fumigates* TKF1: Detection of valuable metabolites. Biomass conversion and Biorefinery. 2014; 4: 137-148.
- [43] Mini KD, Mini. K Paul, Mathew J. Screening of fungi isolated from poultry farm soil for keratinolytic activity. Advances in applied sciences research. 2012; 3(4): 2073-2077.
- [44] Satyalakshmi S, Girija Shankar G, Prabhkar T, Satish T. Statistical optimization of keratinase production from marine fungus. Int. J. of Engg. Res. and Appl. 2015; 5(2): 52-58.
- [45] Parihar P, Kushwaha RKS. Decomposition of feathers by some keratinophilic fungi. J. Mycol. Plant Pathology.1999; 29(2): 192-196.
- [46] Parihar P, Kushwaha RKS. Rapid degradation of human hair by *Chrysosporium indicum* isolated from soil of Thailand. In Microbes: Agriculture Industry and environment. (eds. DK Maheswari, RC Dubey, G Prasad & Navneet). Bishen Singh Mahendra Pal Singh Dehradun. pp. 2000; 177-181.
- [47] Kumar J, Kumar P, Kushwaha, RKS. Feather waste degradation by keratinophilic fungi: An alternative

source for protein and amino acid. Adv. Appl. Sci. Res. 2015; 6(11): 160-164.

[48] Kumar J, Sharma A, Kumar P, Kushwaha RKS. Enhancement of soil nutrition using fermented feather and their efficacy on seed germination. Int. J. of Pure and Appl. Biosci. 2017; 5(1): 92-98.

[49] Elmayergi HH, Smith RE. Influence of growth of *Streptomyces fradie* on pepsin-HCL digestibility and methionine content of feather meal. Canadian Journal of Microbiology. 1971; 17:1067-1072.

[50] Willium CM, Lee CG, Garlich JD, Shih JCH. Evaluation of a Bacterial Feather Fermentation Product, Feather-Lysate, as a Feed Protein. Poultry Science. 1991; 70:85-94.

[51] Sharma R & Devi S. Versality and commercial status of microbial keratinases: a review. Reviews in Environmental science and biotechnology. 2018; 17:19-45.

[52] Mini KD, George SM & Mathew J. Screening and selection of fungus for keratinase production by solid state fermentation and optimization of conditions of SSF and formulation of low-cost medium for the production of keratinase by *Aspergillus flavus* S125. Int. J. of Curr. Micrbiol. and Appl. Sc.2015; 4(9): 535-548.

[53] Kanchana R. Farm waste recycling through microbial keratinases. Journal of applied sciences in environmental sanitation. 2012; 7 (2):103-108.

[54] Onifade AA, Al-Sane NA, Al-Musallam AA and Al-Zarban S. A Review: Potentials for biotechnological applications of keratin-degrading microorganisms and their enzymes for nutritional improvement of feathers and other keratins as livestock feed resources. Bioresource Techno. 1998;66: 1-11.

[55] Sivakumar T, Shankar T, Thangapandian V, Ramasuubramanian V. Optimization of cultural condition for keratinase production using *Bacillus cereus* TS1. Insight Microbiology.2013; 3(1): 1-8.

[56] Manju R. Isolation, identification, characterization of *Bacillus cereus* 4080 LBK producing the keratinase enzyme. Global research analysis. 2013; 2(2): 186-187.

[57] Mehta RS, Jholapara RJ, Sawant CS. Isolation of a novel feather degrading bacterium and optimization of its cultural conditions for enzyme production. International journal of pharmacy and pharmaceutical sciences. 2014; 6(1):194-201.

[58] Summers JD, S J. Singer, Ashton GC Evaluation of meat and feather meal for the growing chicken. Can. Animal Sci. 1965; 45:64-70.

[59] Fisher M, Leeson S, Morrison WD and Summers JD. Feather growth and feather composition of broiler chickens. Can. J. Anim. Sci. 1981; 61: 769-773.

[60] Urdaneta-Rincon M and Leeson S. Effect of Dietary Crude Protein and Lysine on Feather Growth in Chicks to Twenty-One Days of Age. Poultry Science Association, Inc. 2004; 1713-1717.

[61] Kumar DJM, Priya P, Balasundari SN, G.S.D. Nandhini Devi. Production and Optimization of Feather Protein Hydrolysate from *Bacillus* Sp. MPTK6 and Its Antioxidant Potential. Middle-East Journal of Scientific Research.2012; 11(7):900-907.

[62] Hasni MS, Sahito MA, Menon MA, Sanjrani MI, Gopang MA, Soomro MA. Effect of Feeding Various Levels of Feather Meal as a Replacement of Fish Meal on the Growth of Broiler. International Journal of Agriculture

Innovations and Research. 2014; 3 (2):
505-511.

[63] Wiradimadja R, Rusmana D,
Widjastuti T, Mushawwir A. Chicken
slaughterhouse waste utilization
(Chicken feather meal treated)
as a source of protein animal feed
ingredients in broiler chickens.
University of Agricultural Sciences
and Veterinary Medicine Iasi. 2014; 62:
120-124.

[64] Adejumo IO, Adetunji CO,
Ogundipe K and Osademe SN. Chemical
Composition and amino acid profile of
differently processed feather meal. J. of
Agri. Sc. 2016; 16(3): 237-246.

[65] Tesfaye T, Sithole B, Ramjugernat D.
Valorisation of chicken feathers: a
review on recycling and recovery route
current status and future prospects.
Clean Tech. Environ. Policy 2017; DOI
10.1007/s10098-017-1443-9.

[66] Pfeuti G, Osborne V, Shoveller AK,
Ignatz EH, Bureau DP. Development of
a Novel Enzymatic Pre-treatment for
Improving the Digestibility of Protein
in Feather Meal. Agri Engineering.
2019; 1:475-484; doi: 10.3390/
agriengineering1040034.

[67] Naveed A, Sharif M, Sultan JI.
Biological Evaluation of NaOH Treated
and Un-Treated Feather Meal
in Broiler Chicks. Austin J Nutr.
Metab.2019;6(2): 1-5.

[68] Nursinatrio, Nugroho RA.
Hydrolyzed Chicken Feather Meal
as Protein Source for Red Tilapia
(Oreochromis sp.) Aquafeeds. Pakistan J
Zool. 2019; 51(4):1489-1496.