# VALORISATION OF CHICKEN FEATHERS: RECYCLING AND RECOVERY ROUTES

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SUMMARY: The poultry industry generates large amount of feathers as a waste by-product. Small amounts are often processed into valuable products such as feather meal and fertilisers and the remaining waste is disposed of by incineration or by burial in controlled landfills. Improper disposal of these biological wastes contributes to environmental damage and transmission of diseases. Economic pressures, environmental pressures, increasing interest in using renewable and sustainable raw materials, and the need to decrease reliance on non-renewable petroleum resources behove the industry to find better ways of dealing with waste feathers. A closer look at the structure and composition of feathers shows that the whole part of a chicken feather (rachis and barb) can be used as a source of a pure structural protein called keratin which can be exploited for conversion into a number of high-value bioproducts. Thus, conversion of the waste into valuable products can make feathers an attractive raw material for the production of bioproducts. In this review, possible applications of chicken feathers in a variety of technologies and products are discussed. Their valorisation can result in their sustainable conversion into high-value materials and products on the proviso of existence or development of cost-effective technologies for converting this waste into the useful products.

## 1. INTRODUCTION

There is a critical need and increasing interest across the world to decrease the consumption of petroleum-based products and to develop bioproducts using renewable and sustainable sources (Robertson, 2012). Many such efforts have already been made and practised in both developing and developed countries. Such efforts are necessary to satisfy the food, clothing, pharmaceutical, automobile, cosmetic, plastic and other basic needs of the future generation. Due to limited fossil resources, the recent focus is to utilise agricultural by-products and co-products as a replacement in industrial applications. These products are inexpensive (waste materials) and environmentally sustainable renewable resources for use in the development of bioproducts. The food and agricultural industries generate massive amounts of wastes. In addition to the food and agricultural wastes produced during agricultural processing, households produce up to 42 % of the waste, 38 % of the generation of the food waste occurs during food preparation, and 20 % is generated along the food processing chain (Baiano, 2014). At present, legislations around the world encourage valorisation of waste and by-products of manufacturing

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processes (Baiano, 2014). This valorisation of waste can be accomplished through the extraction of new value chains from the waste, for example, fibre filaments, polysaccharides, flavour mixes, proteins and phytochemicals, which can be re-utilized in the nutrition, textile, cosmetic, composite materials and pharmacological functional industries (Ambrose and Clanton, 2004).

The chicken meat processing industry is developing at a rapid growth rate all over the world. Reasons for the great pace include efficient feed to weight gain ratio, the fast growth rate of chickens, poultry being a rich source of nutrients for human consumption, fast production time, and low economic value of poultry per unit (Rahayu and Bata, 2015). Almost all sections of the society, encompassing all customs and religions, consume chicken. According to figures available from the USA Foreign Agricultural Service post reports, the total domestic per capita consumption of chickens is 59 kg in the United States; 48.0 kg in Saudi Arabia, 67.1 kg in Hong Kong, 69.7 kg in Israel, and 35.4 kg in Canada (USDA Foreign Agricultural Service, 2014). In South Africa, the consumption rate for chicken in 2011 was 36.27 kg (DAFF, 2014). This large consumption of chicken results in the generation of huge amounts of chicken feathers each year worldwide. Unfortunately, the demand for use of feathers is rather low, and most of them are disposed of by burning, landfilling, or conversion into feather meal and fed to livestock or used as fertiliser (Gurav and Jadhav, 2013).

In this report, we review some possibilities of use and conversion of chicken feathers into high-value products. Since poultry feathers are rich sources of keratin proteins and amino acids, we believe that they are a valuable resource – their valorisation can result in their sustainable conversion into high-value materials and products on the proviso of existence or development of cost-effective technologies for converting this waste into useful products.

## 2. CURRENT STATUS

### 2.1 Disposal techniques

#### *2.1.1 Incineration*

Incineration is a thermal destruction technology that is one of the most effective methods for destroying conceivably infectious agents. Analysis led by the North Carolina Department of Environment and Natural Resources found that a 57 MW poultry waste burning plant emitted levels of carbon dioxide ($CO_2$), nitrogen oxides ($NO_2$), particulate matter (PM), and carbon monoxide (CO) per unit of power generated, that were higher than those for new coal plants (Stingone and Wing, 2011). Thus disposal of feathers by incineration is not ideal.

#### *2.1.2 Burial and controlled landfilling*

Burial and controlled landfilling of chicken feathers on farms should be strictly monitored to ensure that there will be no groundwater contamination. Since the operation, monitoring, and control of land filling are tightly regulated, landfilling must be prevented as much as could reasonably be expected because of its unfriendly consequences for the nearby environment, especially the contamination of surface water, groundwater, soil and air. Every one of these measures may increase the expenses of landfilling (Veerabadran et al., 2012).

### 2.2 Utilisation

*2.2.1 Feathers as fertiliser*

Feathers contain more than 13 % nitrogen content (Tamrat et al., 2017); this is higher than the best quality blood meal also utilised for such purposes, hence feathers are suitable for compost purposes (Choi and Nelson, 1996). Thus, feathers are used in plant growing operations that require rich nitrogen dressings. Unfortunately, feathers are highly cross-linked with cysteine linkages and difficult to degrade (Park et al., 2000). Their tough, fibrous structure is ineffectively processed by most protein-degrading compounds, however, when blended with compost they degrade well (Gurav and Jahav, 2013). At the point when the feathers are composted, their produced by-products do a reversal as organic matter into the land which further adds to the soil fruitfulness. They form an important poultry composite blend in light of the fact that they add nitrogen, a critical fertiliser component (Veerabadran et al., 2012).

*2.2.2 Feather meal as a feedstock*

Most feathers are not suitable for the aforementioned applications due to their hazardous nature (presence of microbiological pathogens) and their poor digestibility if land filled. Therefore, the fundamental strategy for feather waste management is their conversion into feather meal to be utilised as feedstock. For the production of feather meal, the rachis of the feathers must be broken down by hydrolysis to make them digestible (Table 1) (El Boushy et al., 1990).

Table 1. Compositions of feather meal (McCasland and Richardson, 1966).

| Composition | Percentage |
|---|---|
| **Protein** | 92.3 % (ranges 70-80 %) as digestible protein. |
| **Moisture** | 5.9 % |
| **Fat** | 1.3 %. |

## 3. PHYSICOCHEMICAL PROPERTIES

### 3.1 Physical properties of chicken feathers

Chicken feathers have the lowest density compared to any other natural or engineered filaments commercially available today. Their low density, low thickness, warmth retention property, high compressibility and strength properties, capacity to absorb sound, and particular morphological structure of their barbs make them remarkable fibres (Tamrat et al., 2017; Saravanan and Dhurai, 2012). Besides the special structure and properties, feathers are cheap (waste material), richly accessible and a renewable resource for protein fibre. A feather is essentially comprised of three units; rachis, barbs and barbules as shown in Figure 1. Rachis is the solid and focal shaft of the feather to which the auxiliary structures, the barbs are joined. In the tertiary structures of the feathers, the barbules are joined to the barbs in such a way that the barbs are attached to the rachis. The lengths of the rachis can be up to 15 cm. The barbs have lengths anywhere in the range of 1 to 4.5 cm, contingent upon their location along the length of the rachis. Individual strands at the base of the rachis are longer than those at the tip (Tamrat et al., 2017).

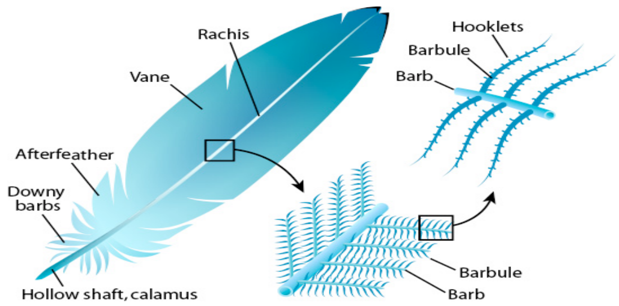


Figure 1. Morphological structure of chicken feathers (Stettenheim, 2000).

### 3.2 Chemical properties of chicken feathers

Chicken feathers contain approximately 91 % keratin, 1 % lipids, and 8 % water. The amino acid sequence succession of a chicken feather is precisely the same as that of reptilian keratins from claws except for the absence of histidine, lysine, tryptophan, glutamic acid and glycine (Saravanan and Dhurai, 2012). Serine (16 %) is the most abundant amino acid in chicken feathers (Saravanan and Dhurai, 2012).

Keratins are insoluble proteins present in rachis, fleece, hooves, scales, hair, nails (hard keratins) furthermore in the stratum corneum (delicate keratins) (Misra and Kar, 2004). These particular proteins, which belong to the scleroprotein groups, are exceedingly impervious to physical, chemical and biological activities. Mechanical stability and high resistance to proteolytic degradation of keratin is because of the presence of disulphide bonds, hydrogen bonds, salt linkages, and cross linkages (Misra and Kar, 2004).

## 4. FUTURE VALORISATION PROSPECTS

The costs to the poultry processing industry to dispose their feather waste are increasingly high due to reduced availability of landfill space. It is very likely in future the industry will not be permitted to dispose of the waste in landfills. For example, the South African government has promulgated legislation for proper disposal and waste minimisation. The National Environmental Management enforces generators of waste to deal with their waste according to the hierarchy of waste management in a sustainable way. That is, every industry will need to re-utilise, recycle, minimise, avoid, treat, and, as an alast resort, dispose of waste (Molapo, 2009). Valorisation of waste feathers can take advantage of their chemical constituents, their cheapness (free waste), ease of availability, and potential to offer sustainable procedures for their disposal. Examples of how and where chicken feather waste can be a useful resource are described below.

### 4.1 Automobile and aeroplane industries

Modern day material science industries are looking for light weight, low cost and biodegradable raw materials for the manufacture of various parts of automobiles and aeroplanes using environmentally sustainable materials. Currently, most automobile and aeroplane parts are made from petroleum-based raw materials. Owing to remarkable strength properties of feathers and their lightweight characteristics (Tamrat et al., 2017), feathers could be used to produce strong lightweight composites for use in automobile and aeroplane industries.

### 4.2 Textile industry

Scientists are investigating ways to process agricultural and food industry wastes into textile consumer products by replacing natural fibres and man-made fibres. Properties such as high surface area, toughness, flexibility, fine diameter, and durability make chicken feathers valuable resources to replace expensive natural fibres, wood pulp, and synthetic fibres. However, the structural properties of a chicken feather are such that feathers cannot be used as is directly into new products. Even though the whole feather contains keratin, the crystal structure of proteins in barbs is different from that of the rachis (Tamrat et al., 2017; Bonser and Dawson, 1999). Only the barbs have the desirable properties to be used as textile fibre. There are two options to use chicken feathers as a fibre source. The first one is blending chicken feather barb fibres with other fibres for spinning into yarns. This is because chicken feather barbs have fibres that can be processed into yarns (after stripping the barbs from the rachis). The second option could be producing regenerated fibres from the whole chicken feather (Figure 2) after keratin extraction.

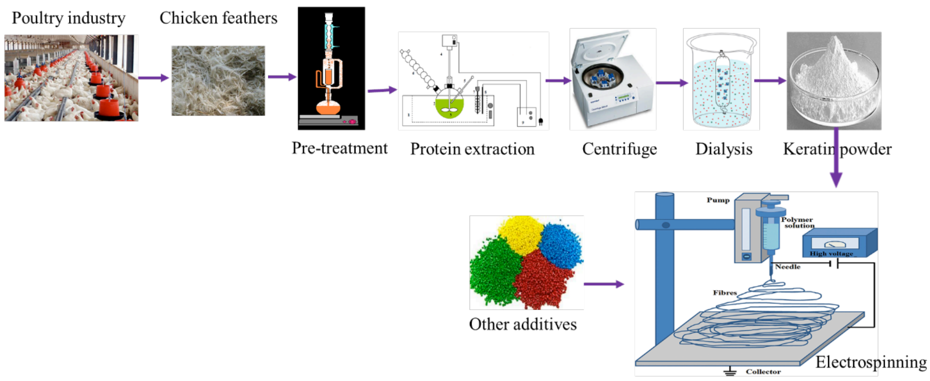


Figure 2. Schematic diagram of regenerated fibre production from chicken feathers.

### 4.3 Plastic and packaging industries

Researchers are working to discover environmentally sourced sustainable materials to replace fossil-based ones (Jin et al., 2011). One possible route is to utilise renewable waste resources to make biodegradable bioplastics. Feathers are inherently non-thermoplastic and do not melt, but simple alkaline hydrolysis makes them thermoplastic and thus suitable for conversion into films after cross-linking, e.g., using citric acid (Tamrat et al., 2017; Misra, 2004). Another route could be graft polymerization using acrylic monomers to impart thermoplasticity that could allow the feathers to be converted into films (Figure 3). What makes chicken feathers ideal is that they are rich in keratin, a tough natural protein polymer composed of natural monomers. In contrast to other biological sources such as plant proteins and modified starch, keratin based plastics could offer greater strength and tear resistance properties because of the tough keratin protein crystallinity structure.

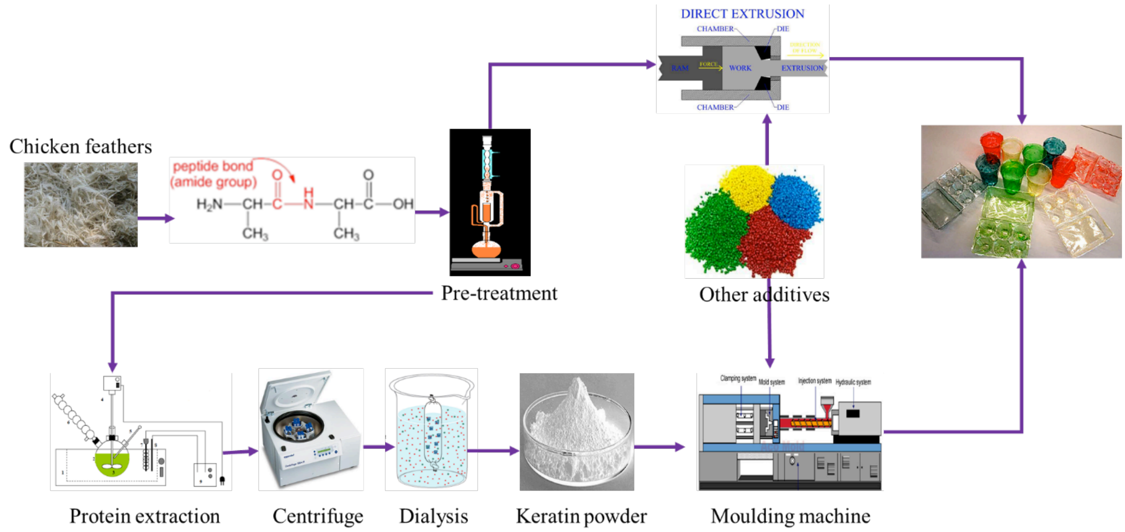


Figure 3. Schematic diagram of bioplastic production from chicken feather

## 4.4 Bioenergy production

*4.4.1 Biogas:* Chicken feathers contain high amounts of crude protein, carbon, nitrogen and hydrogen (Tamrat et al., 2017). Proteins are composed of amino acids linked by peptide bonds, which are hydrolysed by proteases upon decomposition. The degradation products include short or branched chain organic acids, $NH_3$, $CO_2$ and $H_2$. Figure 4 shows the process flow for the production of biogas from chicken feather waste.

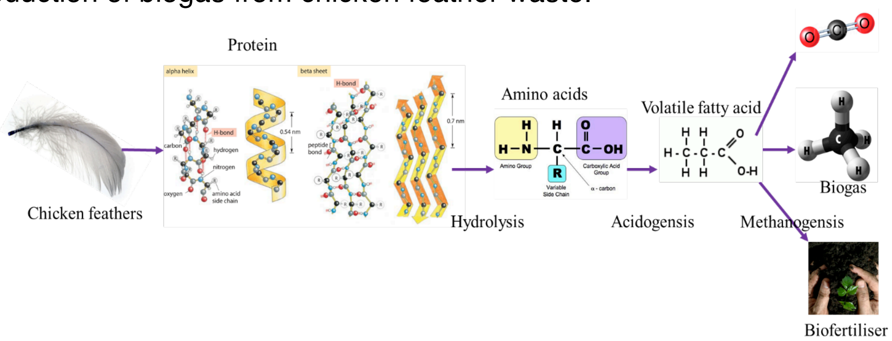


Figure 4. Schematic process flow of biogas production from chicken feathers

*4.4.2. Biofuels:* The world man is facing two major challenges: waste disposal and the need for an abundant source of clean energy. A perfect solution to both of these problems could be to turn the waste into energy which could significantly cut carbon emissions while replacing the need for fossil fuels. Soybean, corn, sunflower and cottonseed are the primary sources of renewable energy via biodiesel production. However, the use of these raw materials faces social problems as their use competes with the food market (Demirbas, 2008). Thus, finding alternative non-food raw materials for biofuel production is a priority. Chicken feathers contain substantial amounts of fat that could be processed for the production of biodiesel (Figure 5). This energy from waste could cut carbon emissions by a large percent while replacing the need for large amounts of petroleum.

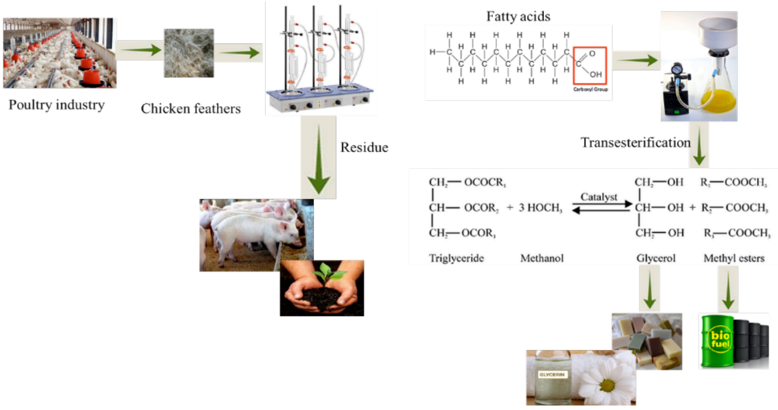


Figure 5. The schematic process flow of production of biofuel from chicken feather

## 4.5 Biomedical engineering

Acceptability by the human body is the first essential requirement of materials to be used in biomedical applications (Rouse and Van, 2010). Chicken fibres are comprised of 91% keratin protein (Tamrat et al., 2017; Reddy et al., 2014) - this protein is the foundation for various biomedical applications including drug delivery carriers, tissue engineering, and self-assembled nanofibrous scaffolds for medical applications (Figure 6). Chemical, biological and physical properties of chicken feathers make them amenable for conversion into biomaterials for use in biomedical applications. The biomaterials would have desirability such as properties include biodegradability, bioresorbability, biocompatibility, serialisability, functionality, self-assembly, as well as mechanical and thermal properties (Ambrose and Clanton, 2004).

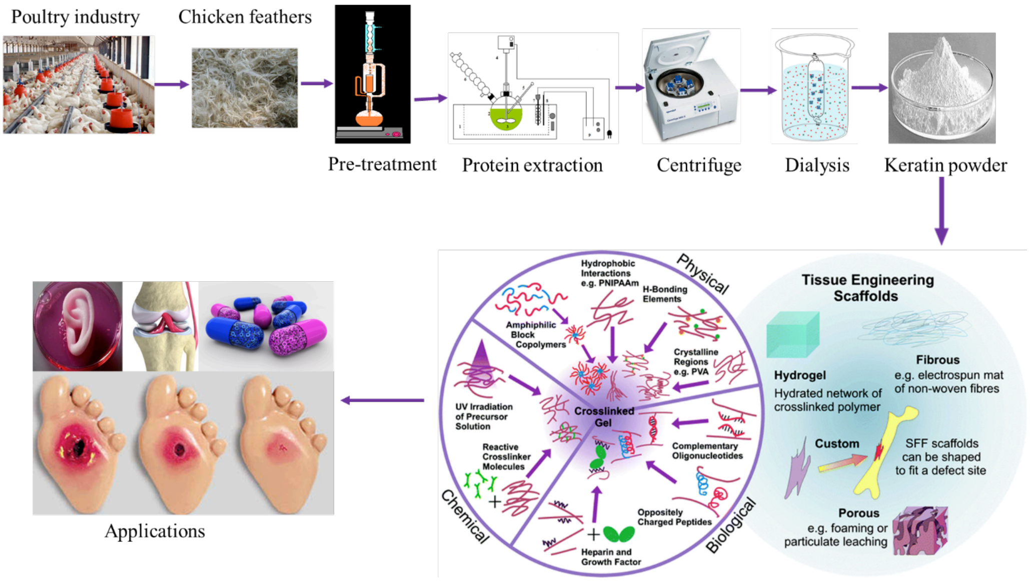


Figure 6. Schematic diagram of biomedical products production from chicken feather

## 4.6 Enzyme production

Keratinase is a proteolytic enzyme that attacks disulphide bridges to convert keratin from complex to simplified forms (Figure 7) (Villa et al., 2013; Paul et al., 2014). Keratinases are used in a wide variety of applications such as for de-hairing of skins in leather manufacturing, fertilisers, or animal nutrients in the agricultural industry, food supplements in the food industry, textile processing, detergents, and in biomedical and pharmaceutical industries. Thus, chicken feathers could be used as a raw material to produce cheap keratinase enzymes since they contain high protein content, and keratin is the raw material for keratinase.

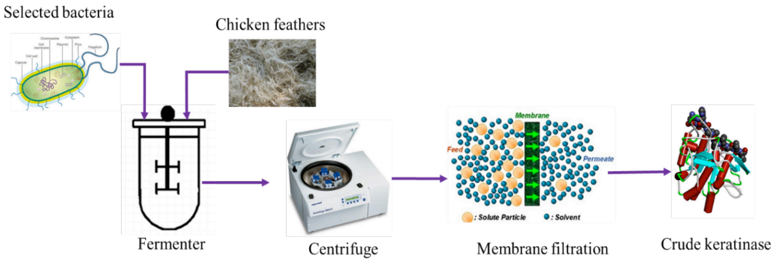


Figure 7. Schematic diagram of keratinase production from chicken feather

## 5. CONCLUSIONS

Chicken feathers are produced in large quantities as a by-product at poultry processing plants. Their disposal by incineration or landfilling is fraught with problems, e.g., environmental pollution and transmission of diseases due to microbial contamination. However, chicken feathers are composed of materials and components (protein and keratin fibres) that can be valorised into a large and diverse variety of valuable products and materials. Using waste chicken feathers to extract high-value materials such as keratin proteins and fibres will minimise environmental pollution as well as reduce reliance on the use of petroleum based products. Extensive research and development work is required to develop appropriate technologies for their full utilisation as a resource for the proposed applications mentioned in this review.

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## REFERENCES

Ambrose, C.G. and Clanton, T.O., 2004. Bioabsorbable implants: review of clinical experience in orthopedic surgery. Annals of Biomedical Engineering, 32(1), 171-177.

Baiano, A., 2014. Recovery of biomolecules from food wastes—A review. Molecules, 19(9), 14821-14842.

Bonser, R.H. and Dawson, C., 1999. The structural mechanical properties of down feathers and biomimicking natural insulation materials. Journal of Materials Science Letters, 18(21), 1769-1770.

Choi, J. and Nelson, P.V., 1996. Developing a slow-release nitrogen fertiliser from organic sources: III. Isolation and action of a feather-degrading actinomycete. Journal of the American Society for Horticultural Science, 121(4), pp. 639-643.

Compassion in world farming, 2013. Statistics: Broiler chickens, www.ciwf.org.uk/media/5235303/Statistics-Broilerchickens.pdf [accessed 18 July 2015].

DAFF, 2014. Department of Agriculture, Forestry and Fishery, 2014. A profile of the South African broiler market value chain, www.nda.agric.za/doaDev/sideMenu/Marketing/Annual%20Publications/Commodity%20Profiles/Livestock/Broiler%20market%20value%20chain%20profile%202014.pdf [accessed 27 Jan 2016].

Demirbas, A., 2008. Biofuels sources, biofuel policy, biofuel economy and global biofuel projections. Energy Conversion and Management, 49(8), 2106-2116.

Edwards, D. and Daniel, T., 1992. Environmental impacts of on-farm poultry waste disposal—A review. Bioresource Technology, 41(1), 9-33.

ElBoushy, A., Van DerPoel, A. and Walraven, O., 1990. Feather meal—A biological waste: Its processing and utilisation as a feedstuff for poultry. Biological Wastes, 32(1), 39-74.

Gurav, R.G. and Jadhav, J.P., 2013. A novel source of biofertiliser from feather biomass for banana cultivation. Environmental Science and Pollution Research, 20(7), 4532-4539.

Jin, E., Reddy, N., Zhu, Z. and Yang, Y., 2011. Graft polymerization of native chicken feathers for thermoplastic applications. Journal of Agricultural and Food Chemistry, 59(5), 1729-1738.

McCasland, W.E. and Richardson, L., 1966. Methods for determining the nutritive value of feather meals. Poultry Science, 45(6), 1231-1236.

Misra, M. and Kar, P., 2004. Keratin Fibres and Structures for Nanofiltration. Natural Fibres, Plastics and Composites. New York: Springer, 83-93.

Misra, M., Kar, P., Priyadarshan, G. and Licata, C., 2001. Keratin protein nano-fibre for removal of heavy metals and contaminants, MRS Proceedings, 2001, Cambridge: Cambridge University Press, 1-11.

Molapo, N.A., 2009. Waste handling practices in the South African high-throughput poultry abattoirs. PhD thesis. Free State: Central University of Technology, 21-120.

Park, S.K., Bae, D. and Hettiarachchy, N., 2000. Protein concentrate and adhesives from meat and bone meal. Journal of the American Oil Chemists' Society, 77(11), 1223-1227.

Paul, T., Das, A., Mandal, A., Halder, S.K., Jana, A., Maity, C., Dasmohapatra, P.K., Pati, B.R. and Mondal, K.C., 2014. An efficient cloth cleaning properties of a crude keratinase combined with detergent: towards industrial viewpoint. Journal of Cleaner Production, 66, 672-684.

Poopathi, S. and Abidha, S., 2007. Use of feather-based culture media for the production of mosquitocidal bacteria. Biological Control, 43(1), 49-55.

Reddy, N., Chen, L., Zhang, Y. and Yang, Y., 2014. Reducing environmental pollution of the textile industry using keratin as alternative sizing agent to poly (vinyl alcohol). Journal of Cleaner Production, 65, 561-567.

Reddy, N. and Yang, Y., 2011. Potential of plant proteins for medical applications. Trends in Biotechnology, 29(10), 490-498.

Rouse, J.G. and Van Dyke, M.E., 2010. A review of keratin-based biomaterials for biomedical applications. Materials, 3(2), 999-1014.

Ryu, Changkook, Yao Bin Yang, Adela Khor, Nicola E. Yates, Vida N. Sharifi, and Jim Swithenbank. 2006. Effect of fuel properties on biomass combustion: Part I. Experiments—fuel type, equivalence ratio and particle size. Fuel 85(7), 1039-1046.

Saravanan, K. and Dhurai, B., 2012. Exploration on the amino acid content and morphological structure in chicken feather fibre. Journal of Textile and Apparel, Technology and Management, 7(3), 1-6.

Stingone, J.A. and Wing, S., 2011. Poultry litter incineration as a source of energy: reviewing the potential for impacts on environmental health and justice. New solutions: A Journal of Environmental and Occupational Health Policy: NS, 21(1), 27-42.

Stuurman, N., Sasse, B. and Fisher, P.A., 1996. Intermediate filament protein polymerization: Molecular analysis of drosophila nuclear lamin head-to-tail binding. Journal of Structural Biology, 117(1), 1-15.

Sydney, B., 2015. Green chemists use rocket science and chicken feathers to create cow-less leather, www.fastcoexist.com/3023593/green-chemists-use-rocket-science-and-chicken-feathers-to-create-cow-less-leather. [accessed 21 July 2015].

Tesfaye T., Bruce S., Deresh R., and Viren C., 2017. Valorisation of chicken feathers: Characterisation of physical properties and morphological structure. Journal of Cleaner Production, 149, 349-365.

Tesfaye T., Bruce S., Deresh R., and Viren C., 2017. Valorisation of chicken feather: characterisation of chemical properties. Submitted, Waste Management Journal.

Urlings, H., VanLogtestijn, J. and Bijker, P., 1992. Slaughter by-products: Problems, preliminary research and possible solutions. Veterinary Quarterly, 14(1), 34-38.

USDA Foreign Agricultural Service, 2014. The Poultry Site: Global poultry trends 2014, www.thepoultrysite.com/articles/3259/global-poultry-trends-2014-slowing-of-asian-population-growth-to-impact-chicken-consumption/ [accessed 04 January 2017].

Veerabadran, V., Balasundari, S.N., Devi, D.M. and Kumar, D.M., 2012. Optimisation and production of proteinacious chicken feather fertiliser by proteolytic activity of Bacillus sp. MPTK 6. Indian Journal of Innovations and Developments, 1(3), 193-198.

Villa, A.L., Aragao, M.R., Dos Santos, E.P., et al., 2013. Feather keratin hydrolysates obtained from microbial keratinases: effect on hair fibre. BMC Biotechnology, 1472-6750(13), 1-11.