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Valorisation of chicken feathers: Characterisation of thermal, mechanical and electrical properties

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ABSTRACT

Increasing consumption of chicken results in generation of large amounts of wastes that need to be disposed of properly. Chicken feathers constitute about 5–10% of the weight of the chicken and thus they comprise a significant portion of the poultry wastes. Disposal of waste chicken feathers is problematic in that they do not readily degrade after landfilling, there is increasing shortage of landfill space, and they are contaminated with microbial biomass that makes them hazardous waste. Feathers contain ~91% keratin protein and thus, potentially, feathers can be beneficiated into high-value compounds or products comprised of keratin proteins or keratin fibres. Thus, valorisation of feathers could be a viable option for sustainable disposal of the waste. Characterisation of physicochemical properties of the chicken feather is an essential step to identifying possible avenues for valorisation of this waste biomass. While chemical, physical and morphological properties of chicken feathers and related potential valorisation routes have described by the authors, identification of their mechanical, thermal and electrical properties have not been reported and this information is necessary to have a complete and comprehensive characterisation of waste chicken feathers. Hence, in this research, the mechanical, thermal and electrical properties of feathers were determined and evaluated to ascertain suitability of the feathers for production of high-value materials. The feathers and fractions thereof were characterised by TGA/DSC, Instron (material and structural testing), Dynamic Mechanical Analyser, and a two-probe measurement of resistivity instrument. Under heated conditions, the TGA of chicken feathers confirmed the occurrence of three zones of weight loss. The TGA/DSC results revealed a glass transition temperature around 67 °C and a melting temperature ~230 °C in the crystalline phase. The tenacity of chicken feather barbs at maximum load was ~16.93 cN/tex. The results from electrical properties indicated that chicken feather fractions have low conductivity. Overall, the results indicate that chicken feathers have potential to be used in a variety of applications such as electrical insulator materials, yarn production for use in textiles, nonwoven fabric production, filler for winter clothing, geotextile and construction materials.

1. Introduction

Increasing consumption of chicken results in generation of large amounts of wastes that need to be disposed of properly. Chicken feathers constitute about 5–10% of the weight of the chicken and thus they comprise a significant portion of the poultry wastes. USA, Brazil and China are the largest producer in the world with South Africa, Egypt and Nigeria being the largest in Africa (Compassion in World Farming, 2013). On a world scale, it is estimated that 40×10^9 kg of chicken feathers are produced from the slaughter of more than 58×10^9 chickens (Compassion in World Farming, 2013). In South Africa, Statistics 2013, indicates the availability of more than 322 large scale chicken meat processing abattoirs. These poultry farming activities generated more than 258×10^6 kg of feathers (DAFF, 2014). Disposal of waste chicken feathers is problematic in that they do not readily degrade after landfilling, there is increasing shortage of landfill space, and they are contaminated with microbial biomass that makes them hazardous waste (El Boushy et al., 2000; Zhan and Wool, 2011). Feathers contain ~91% keratin protein (El Boushy et al., 2000; Zhan et al., 2011) and thus, potentially, feathers can be beneficiated into high-value compounds or products comprised of keratin proteins or keratin fibres (Arshad et al., 2016a, 2016b; Khosa and Ullah, 2013,

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2014; Kim et al., 2010). Thus, valorisation of feathers could be a viable option to sustainable disposal of the waste.

Characterisation of physicochemical properties of chicken feather is an essential step to identifying possible avenues for valorisation of this waste biomass. While chemical, physical and morphological properties of chicken feathers and related potential valorisation routes have described by the authors (Tesfaye, et al., 2017a; 2017b; 2017c; 2017d), identification of their mechanical, thermal and electrical properties have not been reported and this information is necessary to have a complete and comprehensive characterisation of waste chicken feathers. Hence, in this research, the mechanical, thermal and electrical properties of feathers were determined and evaluated to ascertain suitability of the feathers for production of high-value materials. In this research, results of such comprehensive studies are reported with a focus on understanding the mechanical, thermal and electrical properties of waste chicken feather fractions (barb and rachis) with the ultimate aim of developing valorisation routes for the waste feathers depending on their characteristics.

2. Materials and methods

2.1. Materials

2.1.1. Sample collection

Chicken feathers were collected from 3-week old broiler/meat chickens at a slaughterhouse in Durban, South Africa.

2.1.2. Preparation and decontamination of waste chicken feathers

On collection, the feathers were a wet mass of blood, faeces, skin, flesh and other slaughterhouse residues. They were washed with water at 50 °C to remove easily removable matters and then dried at 60 °C for 24 h and conditioned at a relative humidity of 65 ± 2% and a temperature of 20 ± 2 °C. After drying, barbs were separated by manual stripping from the rachis. A portion of the sample was milled into powder, and the rest left intact. The material was then packed and stored at normal room temperature (20–25 °C) in three groups (whole feather, rachis and barb). Chicken feathers treated with 0.5% w/v SDS (CF3) and H_2O_2 0.5% v/v (CF2) samples were compared with raw chicken feather (CF1), to see the effect of pretreatment on mechanical properties.

2.2. Methods

2.2.1. Thermogravimetric analysis (TGA)

TGA profiles of feathers and fractions were determined using a TA Instruments Q500 unit. The rate of heating, sample weight, mode of heating and temperature range used for this study were 5 °C/min, 10 mg, under nitrogen with a purge flow rate of 50 ml/min, and 30–550 °C respectively.

2.2.2. Differential scanning calorimetry (DSC)

DSC profiles of feathers and fractions were determined using a TA Instruments Q500 unit. The rate of heating, sample weight, mode of heating and temperature range used for this study are 5 °C/min, 10 mg, Nitrogen with a purge flow rate of 50 ml/min and 30–550 °C respectively. The melting temperature (Tm) of a sample can be deduced from a peak in the endothermic direction.

2.2.3. Mechanical properties

Chicken feathers fractions were dried and conditioned at a relative humidity 65 ± 2% and a temperature 20 ± 2 °C. The conditioned samples were tested for bundle strength tenacity and linear density according to the bundle tensile strength (Flat bundle method) – ASTM D1445 (2005). This test method covers the determination of (1) the tensile strength or breaking tenacity of fibres as a flat bundle using a nominal zero-gauge length, or (2) the tensile strength or breaking tenacity and the elongation at the breaking load of cotton fibres as a flat bundle with 1/8-in. [3.2-mm] clamp spacing. The samples were prepared by carefully removing single barbs from the rachis of waste chicken feathers and combed, and then 11.8 mm long feathers were prepared. The bundle tensile test was carried out on an Instron Tensile Tester (Model 3345) at 0 mm gauge length using Pressley clamps with leather facing.

2.2.4. Dynamic mechanical analysis

The dynamic mechanical analysis (DMA) of the chicken feather barbs was done using a Perkin Elmer DMA 8000 DMA dynamic mechanical analyser. Feather barbs were tested in the tensile mode, while heating from 20 °C to 200 °C at a heating rate of 2 °C min^{-1}, and at a frequency of 1 Hz.

2.2.5. Electrical properties

The electrical properties of the chicken feather fractions were carried out using the Two Probe Method. This is a standard and most commonly used method for the measurement of resistivity of very high resistivity samples – near insulators. Samples were air-conditioned and measurement was carried out at relative humidity 65 ± 2% and a temperature of 22 ± 2 °C. The instrument used was a Keithley 4200 semiconductor characterisation system from Cascade Microtech Inc. USA.

3. Results and discussions

3.1. Thermal properties

3.1.1. Thermogravimetric analysis (TGA)

The thermal stabilities of the chicken feather and its fractions were investigated by TGA and the results are shown in Fig. 1 where it can be seen that the weight loss profiles of all three feather fractions were similar. Thus, the thermal behaviour of chicken feathers can be described in three main steps:

The first step is due to loss of moisture (12.9–13.4%) in the 25–230 °C temperature range. It is recognised that there are three different types of water within chicken feathers, namely, free water, loosely bonded water, and chemically bonded water which contribute to the conformational stability of keratin protein (Éhen et al., 2004; Wortmann et al., 2006). Consequently, the loss of water, as recorded by the thermogravimetric curve, is the result of the overlapping of three different processes by which the three types of water are lost (Wortmann et al., 2006).

The second step is due to partial decomposition of the feather fractions in the 230–380 °C temperature range with mass losses of ~46%. This loss is due to thermal denaturation of peptide bridge and protein chain linkages: a complex process that includes thermal

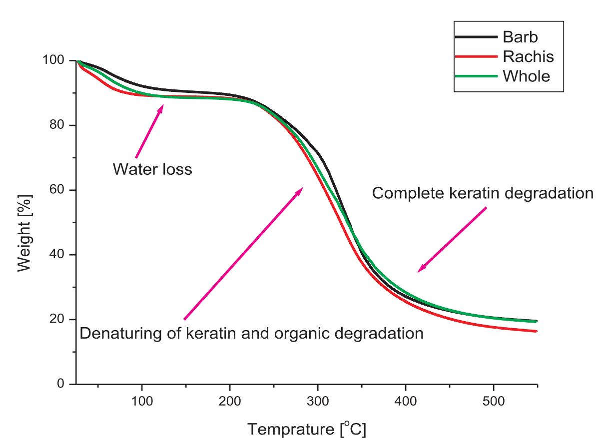

Fig. 1. TGA curve for chicken feather fractions.

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