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The Machine Method for Processing Chicken Feathers by Splitting them into Fibers and Rachis

Tavuk Tüylerinin Makine ile Lif ve Sap Kısımlarına Ayrıştırılarak İşlenmesi Yöntemi

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THE MACHINE METHOD FOR PROCESSING CHICKEN FEATHERS BY SPLITTING THEM INTO FIBERS AND RACHIS

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ABSTRACT: Chicken feathers are obtained as a by-product in the production of poultry meat. Due to its stiffness, fragility and inelasticity, chicken feathers are not considered a valuable material and are mostly industrial waste, the volume of which is increasing. Therefore, chicken meat producers are trying to get rid of them in every possible way. In recent years, instead of getting rid of chicken feathers, research has been carried out towards using their wonderful properties from nature. Among these studies, a special place is occupied by the production of fibers from chicken feathers, which could be used in the textile industry. The presented work concerns the development of a mechanized method for the production of fiber from chicken feathers on an industrial scale. The proposed method is based on the separation of the fibrous part of the feather from the stem of the feather by mechanical cutting using an aerodynamic disperser. With this method, protein fibers with many valuable properties have been obtained, the weight of which is half that of chicken feathers. In addition to these fibers, called chicken feather fibers, a feather stalk is obtained as a by-product, which, due to its lightness and strength, is a suitable raw material for the production of composites. In this work, the properties of the products obtained by the above-mentioned method were studied, and it was determined that the materials obtained as a result of processing the produced chicken feathers are raw materials suitable for industrial use. The production parameters of the machine used to separate the fibers from the stem were also investigated and it was observed that the operating parameters of the machine did not adversely affect the natural properties of the fibers produced.

Keywords: chicken feather, chicken feather fibers, chicken feather rachis, feather processing.

TAVUK TÜYLERİNİN MAKİNE İLE LİF VE SAP KISIMLARINA AYRIŞTIRILARAK İŞLENMESİ YÖNTEMİ

ÖZET: Tavuk eti üretiminde yan ürün olarak ortaya çıkan tavuk tüyü değerli bir hammadde olarak görülmediğinden çok büyük bir kısmı atık durumundadır ki, tavuk eti üreticileri yakma veya toprağa gömme yoluyla onlardan kurtulmaya çalışıyorlar. Son yıllar tavuk tüylerinden kurtulmak yerine bu tüylerden faydalı bir şekilde yararlanılması ve onlara kullanım alanları bulunması daha çok dikkat çekmektedir ve bu yönde çok sayıda araştırmalar yapılmaktadır. Bu araştırmalar arasında tavuk tüylerinden tekstilde kullanılabilir liflerin üretimi özel bir yer almaktadır. Sunulan çalışma, tavuk tüylerinden sanayi çapında lif üretimi için bir makineli yöntemin geliştirilmesi ile ilgilidir. Önerilen yöntem, aerodinamik dispergatör esaslı bir makine kullanarak tavuk tüyünün omurgasını teşkil eden tüy sapından tüyün lifsi kısmının mekanik kesme yoluyla ayrıştırılmasına dayanmaktadır. Bu usulle tavuk tüyünün ağırlığının yarısı ağırlıkta birçok değerli özelliklere sahip protein lifleri elde edilmiştir. Tavuk tüyü lifleri olarak adlanan bu liflerin yanı sıra yan ürün olarak tüy sapı elde edilmektedir ki, değerli özelliklerinden dolayı kompozit üretimi için elverişli ham maddedir. Makalede söz konusu yöntemle elde edilen ürünlerin özellikleri incelenmiş, üretilen tavuk tüylerinin işlenmesiyle elde edilen malzemelerin endüstriyel kullanıma uygun hammaddeler olduğu tespit edilmiştir. Liflerin tüyden ayrıştırılması için kullanılan makinenin üretim parametreleri da incelenerek, makinenin çalışma parametrelerinin üretilmiş liflerin özelliklerini olumsuz yönde etkilemediği görülmüştür.

Anahtar kelimeler: tavuk tüyü, tavuk tüyü lifleri, tavuk tüyü ekseni, tüy işleme.

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1. INTRODUCTION

Chickens are the first in the list of domesticated animals in the world in terms of total number [1]. Statistical data show that in 2018, 65 billion chickens were slaughtered for poultry production and this figure has been increased by an average of 2% per year [2]. Chicken feathers that appear as a by-product during cutting constitutes of 5.5 million tons per year. These feathers are not considered a valuable raw material, and therefore very little part is used. Due to the high protein content in chicken feathers, it is partly used in fertilizer, animal feed and enzyme production, but a significant part of it is discarded [3-5]. In general, the rest of this material that cannot be used is buried or burned to turn into fertilizer, which causes serious damage to the environment [6]. The reason for this is the fact that chicken feathers, which are formed in large quantities during the growing and slaughter of poultry, pose a threat to the environment due to the presence in their composition of the complex-degradable structural protein keratin and the presence of a large number of microbiological pathogens [7Piskaeva]. As a way to get rid of chicken feathers, which increase every year, some researchers began to breed chickens without feather cover [8]. However, such chickens can be raised only in regions with a warm climate. On the other hand, the effect of these chickens on human health has not been fully studied.

Instead of getting rid of chicken feathers in recent years, more attention is drawn to the idea of capitalizing on these feathers and finding new uses for them. This has led to the emergence of serious research on the path to the volarization of chicken feathers, especially in the last 20 years.

Recently, there has been lots of researches on the development of composite materials using chicken feathers. In a number of works, whole feathers were used as a reinforcing material. Reddy and Yang made light‑weight composites reinforced with whole chicken feathers and proved to have high mechanical properties [9]. Amieva et al. produced composites reinforced with chicken feathers from recycled polypropylene [10].

In some works, crushed feathers were used as a reinforcing material. For example, Huda and Yang fabricated a composite shredded chicken feather and polypropylene (PP) and compared the composite performance to a jute-PP composite. It was found that chicken feather is better compatible with polypropylene compared to jute [11].

Quite a lot of work on the development of composites using chicken feather fibers. Barone and Schmidt prepared Polyethylene-based composites using keratin fibers obtained from chicken feathers [12]. Martínez-Hernández *et al*. prepared Polymethyl methacrylate composites reinforced with natural protein biofibers from chicken feathers, which evaluated through a series of tensile tests [13]. Jerrold *et al*. made medium density fiberboard (MDF) panels with aspen fiber and chicken feather fiber, using 5% phenol formaldehyde resin as the adhesive [14]. Uzun *et al*. developed fiber reinforced vinyl ester and polyester composites and evaluated the mechanical properties [15].

In some works, chicken feather fibers have been used to make green composites. Cheng *et al*. made a composite by reinforcing polylactic acid with chicken feather fibers [16]. Baba and Ozmen in their work describe the preparation green composites using Extrusion and an injection molding process in polylactic acid matrix including chicken feather fiber as reinforcement [17].

Although these studies are still at the laboratory level, they open up serious perspectives on the introduction of chicken feathers to the industry. Chicken feathers have some important natural properties, which make the material much more valuable. Among these features, it is necessary to record the cell structure in the feathers [18-19]. Due to this structure, chicken feathers are thought to have good insulation potential. However, chicken feathers in their natural form are not considered very suitable material for use as raw materials. Unlike goose and duck down used as fillers in winter clothes, quilt and pillow, these feathers are distinguished by their fragility, weight, roughness and low elasticity. All these makes it inconvenient to use chicken feathers as a filling material. It should be emphasized here that chickens do not have fluff feathers, as they are not water birds and do not have the ability to fly over long distances. Accordingly, the processing of chicken feathers, which are mainly waste, to a more suitable form for use, attracts more and more attention of both environmentalists and industrialists.

It is recommended to separate the fibrous material branching from the rachis part forming the body of the feather by mechanical cutting. This fiber material, called ‘chicken feather fibers’, has a more universal character in terms of usage. There have been many studies on chicken feather fibers in recent years. In these studies, the structural, physical and chemical properties of chicken feather fibers were examined [3, 20-25].

Although economic evaluations on the production of fiber and particles of rachis from chicken feathers have not yet been made, it is clear that these fibers produced from raw material in waste status will be extremely low cost. One of the main reasons why these evaluations have not been made yet is that no industrial method of cutting the fibrous part of the chicken feathers from the rachis is developed. It is true that, there have been some studies in this direction. Gassner et al. received a patent in 1998 for a machine that produces fiber from bird feathers [26]. In the patent, a machine producing fibers from feathers is depicted. From the description it becomes clear that this machine works on the principle of shredding feather. We remind you that in a number of works, simply comminuted feathers are called feather fibers. During the research, we could not find a machine other than this for the production of fiber from feathers. As it turns out, this machine is not commercialized. Fibers of chicken feathers that were used for research purposes were obtained by cutting feathers with scissors. In some studies, blenders were used for this purpose [27]. But in this case, a mixture of fragments from feathers is obtained, where the fibrous part of the feather does not separate from the rachis. The scheme of such feather shredding is shown in Figure 1*a*.

The presented work relates to an industrial method for separating chicken feathers into fiber mass and feather rachis mass, which are more versatile materials for the point of view of application to industry. For this purpose, we used a machine built on the basis of an aerodynamic disperser. The introduction of this method into production will make it possible to obtain valuable materials such as feather fiber and feather rachis from chicken feathers, which for the most part is in a state of waste production. Chicken feather fibers can be used as filler in winter clothing. This will make it possible to produce products from natural down at a very low cost. These fibers can be used as raw materials for the production of insulation and filtration nonwovens, panels for the production of furniture. Feather rachis also has good insulating properties due to its porous internal structure and lightness can be used for the production of insulating materials, composites, as well as in the production of boards for the furniture industry.

2. APPROACH, MATERIAL AND METHOD

2.1. Approach

The structure of chicken feathers leads to the idea that it is possible to separate the fiber part of the feather from rachis by mechanical cutting and use them separately, thereby obtaining two different materials. Studies have shown that the weight ratio of fibrous part to chicken feather rachis is approximately 1:1. Although the protein-containing fibers, that are obtained as a result of such a process, are very diverse in length, they are generally short fibers. These fibers have a natural cellular internal structure, and this structure will lead to the use of these fibers as insulating materials, and will also allow the production of lightweight composite materials from them.

The stalk of the feather, called rachis, gives the feather high hardness, low elasticity, brittleness, etc., and forms the hard part of the feather. The feather processing method we used is based on separating the fibrous part from the rachis by mechanical cutting and collecting each material separately. The parts of rachis that are obtained as a result of processing the feather, just like the fibers of the chicken feather, have lightness and a porous internal structure and can be used for different purposes. The scheme of such a feather trimming is shown in Figure 1*b*.

The process of processing chicken feathers will run at 2 stages: at the first stage, the feathers coming from poultry processing plant will be washed and disinfected, and at the second stage, feathers will be divided into parts of fiber and rachis.

2.2. Materials

Feathers obtained from the "Tad Piliç" operating in Gaziantep region were used as material. The feathers were washed with tap water to remove the dirt on them, dried in the shade, and then delivered to us by (Figure 1*c*).

As you know, chicken feather is a material containing dirt and grease due to the living conditions of chickens. The level of pollution can vary depending on the type of bird, climate and living conditions in the environment in which it grows. Feathers to be recycled must be clean and safe. Therefore, they need to be washed and disinfected. For washing the feathers, we used a non-ionic detergent (ph = 7-8), which easily dissolves in water and is able to remove dirt and grease without damaging the fine structure of the feather.

To disinfect feathers a solution of sodium hypochlorite $NaClO$ with an active chlorine content of 15-16% were used owned by "ARKIM" were used.

2.3. Method

2.3.1. Equipment used

In laboratory studies, the following equipment was used: programmed household washing machine Beko D3 5061; programmable laboratory dryer for feather-down materials (look: 2.3.2); laboratory type machine to separate the fibrous part of the feather from the rachis of the feather (look: 2.3.3); Nuve branded air-conditioning cabinet; OLYMPUS brand CX31 model optical microscope; Zeiss Gemini 500 brand Field Emission Scanning Electron Microscope; SHIMADZU brand strength tester. TG analysis feathers were performed using appropriate Perkin Elmer instrument.

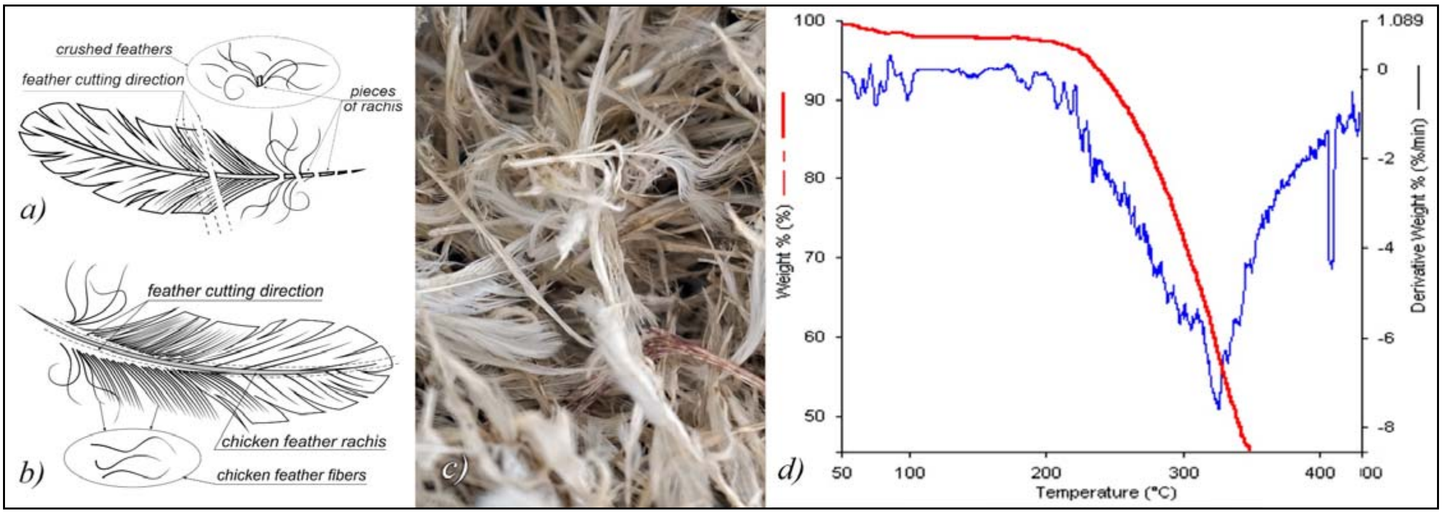

Figure 1. *a*) the scheme of feather comminuting without separating the fibrous part from the rachis, *b*) the scheme of cutting a feather into fibers and rachis, *c*) unwashed feathers, *d*) thermogravimetrically curves of chicken feathers

2.3.2. Cleaning and disinfection of feathers

Feathers were washed in a household washing machine in several stages (Figure 2*a*). In the first stage, the feathers were pre-washed for 20 minutes in 0,48% sodium hypochlorite solution at 21-23°C temperature and then rinsed for 20 minutes with clean water at normal temperature. After that, the feathers were subjected to two main washes with a 0,2% solution of detergent at a pH value of 7-8 at 40°C for 1 hour each. After each main wash, the feathers were rinsed with plain water for 20 minutes.

The amounts of detergent and disinfectant in detergent solutions were established based on the results of early experimental studies [25].

The pH value = 7-8 of the solution was chosen for the following reasons. Feathers after being removed from the carcass of birds begin to deteriorate. While the feather material is transported from the slaughterhouse to us, it takes a certain time. Although in the slaughterhouse the material was rinsed with plain water and dried at our request, nevertheless the degradation of the material continued. After the treatment with NaClO, this process was stopped and so that during the washing process with the feathers no chemical changes occurred, they were washed in a neutral environment.

Therefore, the choice of NaClO for the prewash was did not accidental. Firstly, it is a powerful disinfectant and treatment with a solution of this substance of feathers, if not completely stops, then significantly slows down the process of bacterial degradation of feathers. Secondly, being a strong alkali, it neutralizes a significant part of fatty acids that are formed on the surface of feathers as a result of hydration of fats.

Washing and subsequent drying temperatures are selected based on previously performed thermogravimetric analysis [25]. The results of the analysis showed that starting from a temperature of about 25°C to 50°C, the first weight loss of the sample occurs. This loss, although small, still suggests that certain changes occur in the structure of the samples, which is reflected in the DTGA curve (Figure 1*d*). Based on this, it was decided to set the temperatures of both washing and drying of feathers below 50°C. The analysis results coincide with the literature data [28].

The washed feathers were dried in a programmable laboratory feather dryer machine with hot air. The machine was developed in Department of Textile Engineering Erciyes University by Prof. Dr. N.Paşayev (Figures 2*b* and *c*). Feathers were dried at 40°C for 22 minutes. Starting from the 23rd minute of the process, the temperature in the drying chamber was increased to 75°C for 10 minutes to kill bacteria remaining in the feathers. During the entire drying process, the feathers were treated with an ultraviolet lamp installed in the drying chamber for disinfection.

2.3.3. Separation of feathers into feather fibers and rachis

The machine-separator used to separate the chicken feathers into fiber and rachis of is a dispersing apparatus developed by PC "Parmatech" and modified based on our request for processing chicken feathers. Feathers can be put into the machine manually or taken with a hose using a pump. Without exception, it can separate chicken feathers of all sizes into fibers and rachis and the feathers do not need to be cut into small pieces beforehand. The photo of the machine is given in Figure 3*a*.

The working body of the machine is an aerodynamic disperser, which is located inside the cabin *2* (Figure 3*a*). Thanks to the air flow created by the fan *12*, the feathers are taken into the machine through the port *1* and, continuing to move, enter the dispersion zone. As the feathers pass between the blades, the fibrous portion of one side of the feather is cut and detached

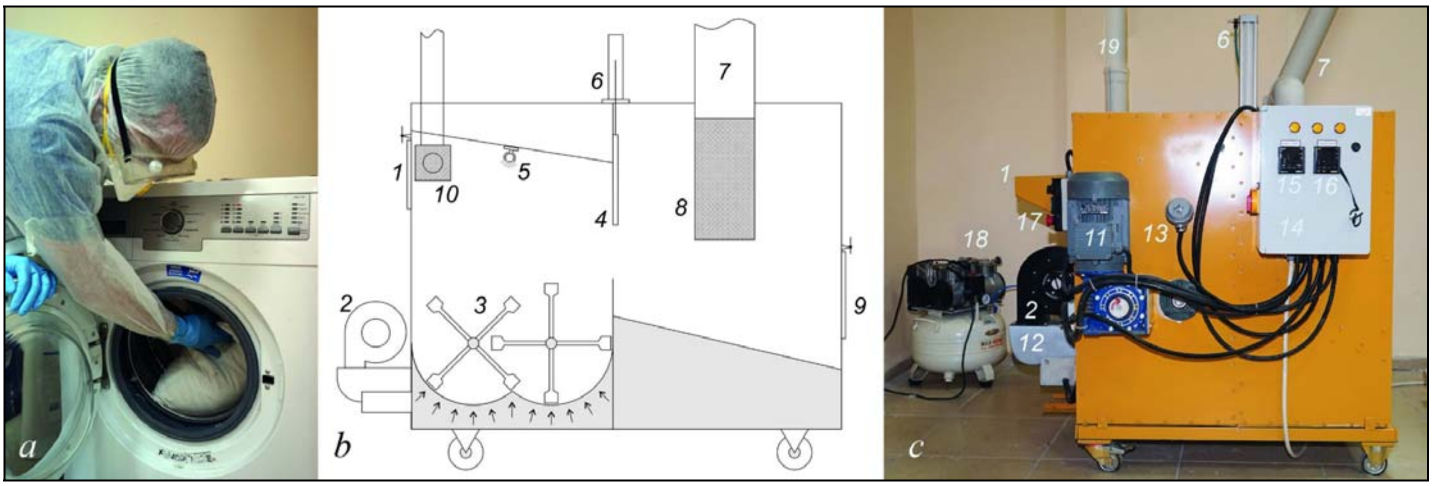

Figure 2. Washing machine (*a*); Schematic (*b*) and photo (*c*) of a feather drying machine: *1* – window for loading feathers into machines; *2* – fan for blowing hot air into the drying area; *3* – feather mixers; *4* – window for the transition of dried feathers to the collection and dedusting area; *5* – UV lamp for antibacterial treatment; *6* – vacuum cylinder for opening and closing the passage window; *7* – dust collector; *8* – chimney for exhaust air and dust; *9* – dry feather extraction window; *10* – window with chimney for steam extraction; *11* – mixer motor; *12* – heating tube for air; *13* – thermocouple; *14* – control panel; *15* – temperature relay; *16* – time relay; *17* – on/off, *18* – compressor; *19* – chimney for removing steam.

from it. The fibers separated from the rachis enter the interior of the disperser and are directed into the outlet channel *3* by the air flow. The feather remaining in the dispersion zone again falls into the contact zone of the blades and the fibrous part is cut from the other side. The fibers again remain inside the disperser and move further in the air flow through channel *3*. The heavier rachis particles leave the disperser under the action of inertial forces and are collected in chamber *4* under the disperser. The fibers move along the pipe *3* and pass through the air flow valve *5* and enter the separating cyclone 6. Here the fibers are separated from the dust particles. Lighter dust particles are removed from the chimney *7* with air and are collected in the outlet by a dust collector. The fibers are collected in the bunker *8* and moved to the collection point using spirals *9*. The dispersant is driven from the engine *11*.

The machine has three managed operating parameters: the rotational speed of the motor shaft that operates the disperser, the angle of rotation of the airflow valve throttle, and the loading percentage of the machine. The parameters are managed from the administration panel *10*. The yield and length of the fibers obtained by managing these parameters are different.

In a previously published study, the working parameters of the machine have been optimized in terms of the length of the fibers produced [29]. It has been determined that the best fiber output in terms of length is obtained from the feathers with humidity of 15% in the optimal working parameters which are given below:

51.2 Hz Rotation frequency of motor shaft;

11.7 Swing angle of valve throttle;

20.6% Machine loading percentage.

2.3.4. Quantity analysis of machine processing results of chicken feathers

1 kg of feathers was taken from the mass of feathers sent from the chicken factory (Figure 1c), washed, disinfected and dried under the conditions indicated above. A sack made of fabric, which is fiber proof, but air permeable, it was attached to the neck of the spiral 10 (Figure 3a) for the output of the fibers. Rachis chamber 2 (Figure 3a) was cleaned thoroughly with a vacuum cleaner. A bag made of dust-proof but air-permeable fabric it was attached to the mouth of the chimney 7 (Figure 3a).

Figure 3. *a*) machine for separating the feather into the fiber and the rachis; *b*) separated feather fiber; *c*) separated feather rachis pieces; *d*) view of the pieces of rachis under the microscope after cutting the fibrous part of the feather

The dried feathers were put into the machine to be separated as fiber and rachis and they were processed in the previously determined optimal operating parameters. After the separation process, the resulting masses of fiber, rachis and feather flour from the chimney were weighed and thus the amounts of fiber, rachis, and feather powder obtained from 1 kg of feathers and the amount of feathers lost as waste were determined. 300 g of samples were taken from each of the obtained fibers and rachis, for further research. They were placed in the air-conditioning cabinet in open containers and kept for at least 24 hours under standard conditions.

2.3.5. Structural analysis of chicken feather fiber and rachis outputs

As a result of the processes that chicken feathers are exposed to the separation process into fiber and rachis particles, it is analyzed whether there is a deterioration in the microporous internal structure. After processing the feathers for this purpose, SEM analysis of fiber and rachis outputs was performed. In order to examine the internal structure, cuts of feather fiber and rachis were obtained using a sharp knife. Uncut and cut fiber and rachis samples were plated with gold/palladium using a special device. ZEISS Gemini 500 branded electron microscope in Erciyes University Technological Research and Application Centre was used in the studies.

2.3.6. Length and diameter analysis of chicken feather fiber and rachis outputs

Within the scope of the study, measurements were made according to method A in ISO 6989-81 standard to evaluate the lengths of chicken feather fibers. Before measurements, the fiber and rachis samples were kept in a conditioning test cabinet for at least 24 hours at (20 ± 2)°C and 65% (65 ± 2) relative humidity.

20 pinches of chicken feather fibers were randomly taken from different parts of the sack containing the produced chicken feather fibers and placed on the table under normal ambient conditions. The fibers were randomly taken from the individual fiber tufts with the help of a tweezer and placed flat on a glass plate, on which some glycerin was smeared on the surface. After measuring the length of the fiber with the metallic ruler fixed on the microscope, the glass plate was placed under the microscope with the fiber and the diameter values being checked (Figure 4*a*, *b*).

The diameter of the fibers was measured according to the ISO 137 standard. As the fiber diameter changes along its length, the diameter values were measured at three points on each fiber and average of diameters was taken. OLYMPUS brand CX31 model optical microscope was used to measure the length and diameter values of the fibers. These processes were repeated for 500 fibers by taking 25 fibers from each tuft.

The measurement results obtained were classified according to fiber length. In terms of fiber lengths, 5 groups were determined: a group with length less than 12mm, a group with a length of 12-16mm, a group with a length of 16-20mm, a group with a length of 20-24mm and a group including fibers over 24mm in length. The length and diameter values of each fiber were measured and the results were transferred to a table.

Chicken feather rachis material emerges during the production of fibers from feathers. As a result of separation, rachis is obtained in the form of pieces, and the length of the pieces varies between 3-40 mm. To carry out the measurements, 20 pinches of rachis samples were taken from the bag and they are placed on the table. 25 samples were randomly taken from each of the 20 tufts. 500 samples in total were taken and their lengths and diameters were measured. To measure the length and diameter of the rachis pieces a digital caliper was used.

Figure 4. Measuring fiber length and thickness with a microscope: *a*) microscope and glass plate with fiber, *b*) fiber under the microscope

The measurement results obtained were classified according to rachis pieces length. In terms of rachis pieces lengths, 5 groups were determined: a group with length less than 5mm, a group with a length of 5-10mm, a group with a length of 10-15mm, a group with a length of 15-20mm and a group including rachis pieces over 20mm in length. The length and diameter values of each piece were measured and the results were transferred to a table.

To determine whether there is a relationship between the length, as well as diameter of the fibers and pieces of the rachis, correlation analysis was used.

2.3.7. Analysis of the mechanical properties of the obtained feather fibers and rachis

The effect of washing, decontamination, separation of the feather into fibers and rachis on their mechanical properties was investigated. The study was conducted in three stages. At the first stage, a quantity of samples was taken from unwashed feathers and washed with clean water at 30°C. The fibrous portion of the feathers, dried under room conditions, was removed with scissors and the resulting chicken feather fibers and rachis were subjected to mechanical tests. After the feathers were washed using chemicals and dried, the same process was repeated and the mechanical properties of both the fiber samples and the rachis samples were tested. At the third stage, the mechanical properties of chicken feather fibers and rachis material obtained by separating chicken feathers using a machine were studied.

For tensile tests, 10 samples were randomly taken from the mass of fibers and rachis material at each stage and subjected to a tensile test at Erciyes University Technological Research and Application Center. The tests were carried out in a SHIMADZU AGS-X ASTM D3822 where single fiber specimens were broken on a tensile tester at a constant tensile rate of 10 mm / min (CRE). The conditioning of the samples to be tested was carried out in accordance with the ISO 139 standard. Using the computer program Trapezium W (Shimadzu), the tests results were converted to data.

The data obtained were subjected to statistical analysis. For this purpose, samples of fibers and rachis were taken from three groups of unwashed and washed feathers. Samples of fibers and rachis from unwashed feathers were obtained by manual separation. Samples from washed feathers were obtained by both manual and machine separation. As a result, three groups of samples were obtained, the mechanical properties of which were compared with each other. For this, a statistical multiple comparison test was used. The analysis was carried out using the Minitab 19 software.

3. RESULTS AND DISCUSSION

3.1. Machine separation of fibers and rachis of feathers

The washed and dried feathers were processed in the machine to separate the fibers and the rachis. The photos the separated fiber and rachis of chicken feathers are given in Figure 3*b* and Figure 3*c*. After cutting the fibrous part of the feather, the view of the pieces of rachis under the microscope is shown in Figure 3*d*.

3.2. Analysis of surface and internal structure of obtaining fibers and rachis

Full, surface and internal structure images of the fibers obtained are shown in Figure 5 and rachis particles in Figure 6.

As seen in Figure 5*a*, chicken feather fibers have a branched structure in their outer appearance. Due to this structure, chicken feather fibers can also be called branched fibers. The internal structure of the fibers consists of pores separated from each other by a thin wall, which have a size of up to 10 micrometers (Figure 5*b*). The walls between the pores also have a porous structure, and the sizes of these pores are from 30 to 200 nanometers (Figure 5*c*). The outer wall of fibers is thicker and denser which its thickness varies in the range of 3-20 micrometers.

As seen in Figure 5, the inner structure of the fibers is not damaged as a result of the process carried out in the separation machine. This allows you to use the resulting material on this machine for insulation purposes.

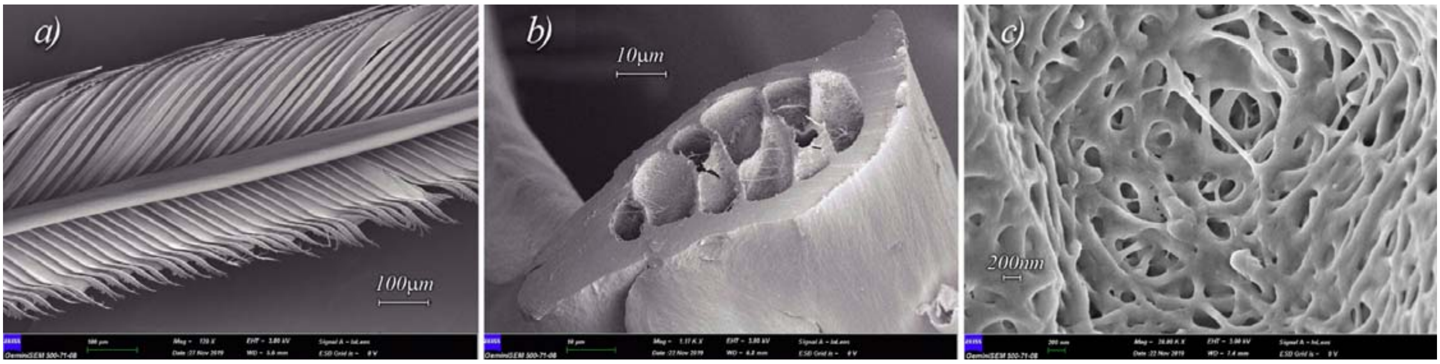

Figure 5. SEM images of chicken feather fiber: *a)* - the outer appearance of the fiber; *b)* - the internal structure of the fiber; *c)* - the walls of the internal structure cells

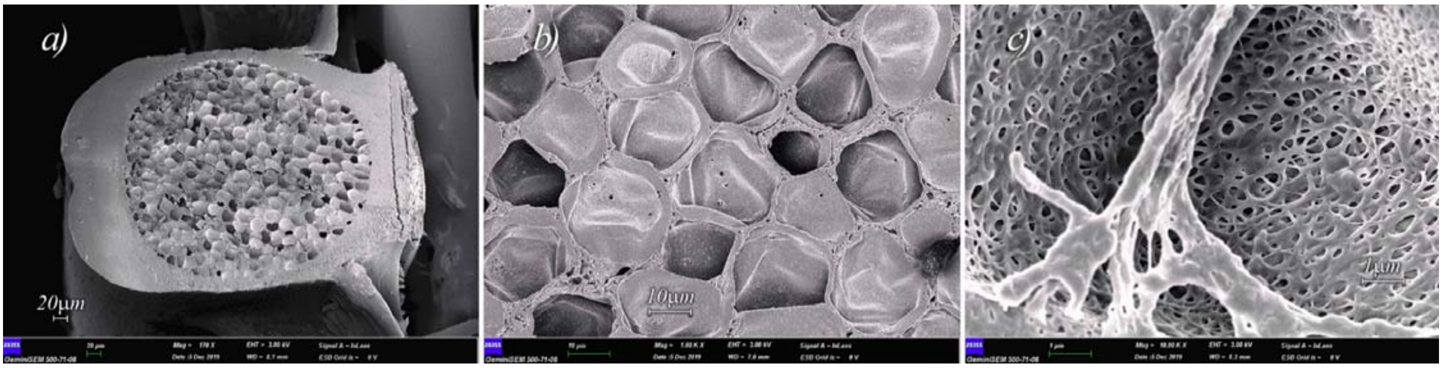

Figure 6. SEM images of chicken feather rachis piece: *a)* - the outer appearance of the rachis; *b)* - the internal structure of the rachis; *c)* - the walls of the internal structure cells

As shown in Figure 5a, chicken feather fiber or the so-called barbs is structurally similar with feather. In the middle, as if in a feather, is the barb rod, on which the barbules are built, the length of which is up to 400 micrometers. Barbules also have a branched structure. On the surface of these barbules there are barbicels up to 50 micrometers long (nomenclature based on [30]). Such a structure to the fibers brings both advantages and disadvantages. It is a disadvantage that this structure prevents the fibers from sticking together which makes yarn spinning from chicken feathers fibers significantly difficult. The advantage is that these fibers, which cannot adhere to each other when bundled, leave gaps between them and these air-filled spaces make the fiber mass a good thermal insulation material. The inability of the fibers to stick together also avoids them felting. Due to the fact that the chicken feather fibers have a porous internal structure, an insulating material of double porosity is obtained. As a result, these fibers emerge as an insulating material that double porosity structure, has a not felting and therefore can serve for a long time. These properties of chicken feather fibers will allow to be utilized these fibers as filling material in winter clothes [31]. Another advantage of the fact that chicken feather fibers have a feather-like structure is that although the fibers are short, their surface area is quite large at 0.7845 m^2/g [32]. This makes composite production from chicken feather fibers attractive.

Figure 6 shows that there are no changes in the surface structure and internal structure of the rachis material after processing the feather in the separator. The thickness of the outer wall of the rachis is 20-100 m, the thickness of the walls between the cells is 0.2-0.6 µm, the size of the cells is 5-25 µm, the size of the pores of the walls between cells is 0.1-0.5 µm. This allows the use of the porous structure of this material in the production of thermal insulation materials. In laboratory conditions, we have made a panel for furniture production from chicken feather rachis, laboratory samples of composites have been made using thermosetting and thermoplastic matrices.

3.3. Results of quantitative analysis of materials obtained in the separator

To determine the quantitative composition of the materials obtained by processing chicken feathers in a separator, the amounts of released fibers, rachis and feather flour were weighed. First of all, it should be noted that these figures are not constant, and we can say from our experience that they may differ depending on the age, breed, feeding conditions of the chickens and the condition of the dispersing blades. As a result of processing from 1 kg of feather, 462.58 g of fiber and 457.54 g of rachis were obtained. 62.27 g of feather flour was collected at the exit from the chimney of the machine. Thus, 98.24% of the feathers in the machine was separated as feather fiber, rachis and feather flour, 1.76% was turned into waste. It was noticed that some of this waste in the form of short fibers, adhering to the rachis parts, went into the rachis collection chamber or remained in the corners and walls inside the machine in the form of fibers, rachis pieces and dust. It took 14 minutes to process 1kg of feather in the working parameters specified above.

3.4. Results of analysis of produced chicken feather fibers in length and diameter

25 fibers were taken randomly from each of the 20 tuft samples taken randomly from different parts of the produced fiber mass. The distribution of these fibers by length is given in Table 1.

Table 1. Distribution of 500 randomly received fibers by length

	Specified length (*l*) ranges for fibres, mm				
	***l*≤12**	**12<*l*≤16**	**16<*l*≤20**	**20<*l*≤24**	***l*>24**
Number of fibers in each length groups, number	31	147	164	132	26
Fiber percentage for each length groups, %	6.20	29.40	32.80	26.40	5.20
Average fiber length for groups, mm	9.13	14.57	18.16	22.25	30.38
Average fiber diameter values for groups, µm	60.35	54.06	42.65	23.72	12.48
Weighted average fiber length, mm	18.26				
Weighted average fiber diameter, µm	40.53				

As seen on Table 1, a significant part of the fibers obtained by the processing of the feathers in the machine is 12-24mm long. Fibers smaller than 12mm and larger than 24mm constitutes about 11,4% of the total fiber mass. In the table for each group of fiber lengths shows the average diameter and length of the fibers.

It is observed that there is a negative correlation between the lengths and diameter values of the fibers, expressed by the coefficient of -0.938. As seen on the table while the length of the fiber increases, its thickness decreases.

The length of the feather fibers depends on the width of the feather, which depends on the location of the feather on the body, its functions, the breed and age characteristics of the chicken, and the nutritional conditions.

The length of the feather fibers coming out of the machine may be slightly shorter than the maximum possible length. On the one hand this is due to the breakage of the fibers during processing, and on the other how closely the fiber is cut into the rachis. Our studies have revealed that it is possible to obtain longer fibers by managing the moisture content of the feathers including in the separating machine during drying [29]. It is estimated that it is possible to increase the fiber length by decreasing the brittleness of the feathers and further studies in this direction are continuing.

3.5. Results of analysis of produced chicken feather rachis in length and diameter

Length and diameter analysis of pieces rachis separated from chicken feathers was done using analysis methods for fibers. For the length and diameter analysis of the pieces rachis 20 pinches of samples were randomly taken from different parts of the rachis mass exiting the machine. The distribution of 25 rachis pieces taken randomly from each of them according to the length is given in Table 2.

According to the results on Table 2, the majority of the rachis particles coming out of the machine are in the range of 5-20mm and the weighted average rachis length constitutes 11.53mm. It was observed that there was a very strong positive correlation between the average length and thickness values of the rachis particles coming out of the machine with the coefficient of 0.978. With increasing thickness, the average length of the particles exiting the machine also increases. Diameter pieces rachis varies in the range of 0.52-1.78mm. As can be seen, unlike the fibers, the correlation here is positive. This is due to the structure of the machine. All the quills passing through the machine due be cut into pieces of the equal length. Due to the fact that there are pieces of rachis which the blades cannot cut or they accidentally pass through the blades, the lengths of the pieces of rachis show changes.

3.6. Results of mechanical analysis of produced feather fiber and rachis

The mechanical properties of the fibers and pieces of rachis obtained manually and by machine from feathers were tested. The maximum applied force, maximum elongation and maximum tension value were measured when testing feather fibers and pieces of rachis on a strength tester.

The normality of the distribution of data in the measurement groups was verified by the Ryan-Joiner test, and the dispersion homogeneity by the Levene test. On the one-way analysis of variance, the hypothesis was confirmed that there is no significant difference between the mechanical parameters of fibers and the rachis materials obtained from feathers by manual and machine methods. The comparisons were made according to the Dunnett test. The comparison was made according to Dunnett's criterion. In this case, a group of samples from unwashed feathers was accepted as a control group.

Statistical processing of the results of mechanical tests for chicken feathers fibers and rachis are presented in tables 3 and 4, respectively. In the tables, samples of fibers and rachis from unwashed feathers that have been manually cut are designated as Y. Samples from washed feathers that are manually cut are designated as Y_e and machine-cut samples as Y_m.

Mechanical indicators are shown on Table 5 with average values.

Table 2. Distribution of 500 randomly received pieces rachis by length

	Length ranges determined for rachis, mm				
	$l \le 5$	$5< l \le 10$	$10< l \le 15$	$15< l \le 20$	$l > 20$
Number of rachis particles in each length groups, number	84	176	149	56	35
Percentage of rachis particles for each length groups	16.8	35.2	29.6	11.4	7.0
Average rachis particle length for groups, mm	3.92	8.23	12.97	18.31	29.32
Average rachis particle diameter, mm, for groups	0.52	0.82	1.04	1.31	1.78
Weighted average rachis pieces length, mm	11.53				
Weighted average rachis pieces diameter, mm	0.96				

Table 3. Statistical processing of the results of mechanical tests for chicken feathers fibers

	Max.Force, N	**Max.Tensile, MPa**	**Max.Elengation, %**
Normality test	Y: RJ=0,971; P-Value>0,1 Ye: RJ=0,960; P-Value>0,1 Ym: RJ=0,978; P-Value>0,1	Y: RJ=0,971; P-Value>0,1 Ye: RJ=0,960; P-Value>0,1 Ym: RJ=0,978; P-Value>0,1	Y: RJ=0,971; P-Value>0,1 Ye: RJ=0,960; P-Value>0,1 Ym: RJ=0,978; P-Value>0,1
Test for Equal Variances: Y; Y_e; Y_m	Method Null hypothesis: All variances are equal Alternative hypothesis: At least one variance is different Significance level: α = 0,05 Tests Method / Statistic / P-Value Multiple comparisons / — / 0,729 Levene / 0,42 / 0,660	Method Null hypothesis: All variances are equal Alternative hypothesis: At least one variance is different Significance level: α = 0,05 Tests Method / Statistic / P-Value Multiple comparisons / — / 0,052 Levene / 2,35 / 0,114	Method Null hypothesis: All variances are equal Alternative hypothesis: At least one variance is different Significance level: α = 0,05 Tests Method / Statistic / P-Value Multiple comparisons / — / 0,229 Levene / 2,06 / 0,147
Analysis of Variance	Method Null hypothesis: All means are equal Alternative hypothesis: Not all means are equal Significance level: α = 0,05 Analysis of Variance Source / DF / Adj SS / Adj MS / F-Value / P-Value Factor / 2 / 602,4 / 301,2 / 2,42 / 0,108 Error / 27 / 3365,9 / 124,7 Total / 29 / 3968,3 Grouping information Using the Dunnett Method and 95% Confidence Factor / N / Mean / Grouping Y (control) / 10 / 0,4023 / A Ye / 10 / 0,4191 / A Ym / 10 / 0,41460 / A	Method Null hypothesis: All means are equal Alternative hypothesis: Not all means are equal Significance level: α = 0,05 Analysis of Variance Source / DF / Adj SS / Adj MS / F-Value / P-Value Factor / 2 / 602,4 / 301,2 / 2,42 / 0,108 Error / 27 / 3365,9 / 124,7 Total / 29 / 3968,3 Grouping information Using the Dunnett Method and 95% Confidence Factor / N / Mean / Grouping Y (control) / 10 / 133,13 / A Ye / 10 / 144,00 / A Ym / 10 / 137,27 / A	Method Null hypothesis: All means are equal Alternative hypothesis: Not all means are equal Significance level: α = 0,05 Analysis of Variance Source / DF / Adj SS / Adj MS / F-Value / P-Value Factor / 2 / 0,0331 / 0,01654 / 0,01 / 0,986 Error / 27 / 30,9052 / 1,14464 Total / 29 / 30,9383 Grouping information Using the Dunnett Method and 95% Confidence Factor / N / Mean / Grouping Y (control) / 10 / 5,202 / A Ye / 10 / 5,168 / A Ym / 10 / 5,121 / A

Table 4. Statistical processing of the results of mechanical tests for chicken feathers rachis

	Max.Force, N	Max.Tensile, MPa	Max.Elengation, %
Normality test	Y: RJ=0,988; P(Value)>0,1 Ye: RJ=0,965; P(Value)>0,1 Ym: RJ=0,982; P(Value)>0,1	Y: RJ=0,988; P(Value)>0,1 Ye: RJ=0,987; P(Value)>0,1 Ym: RJ=0,986; P(Value)>0,1	Y: RJ=0,983; P(Value)>0,1 Ye: RJ=0,970; P(Value)>0,1 Ym: RJ=0,971; P(Value)>0,1
Test for Equal Variances: Y; Y_e; Y_m	Method Null hypothesis: All variances are equal Alternative hypothesis: At least one variance is different Significance level: α = 0,05 Tests Method / Statistic / P-Value Multiple comparisons / — / 0,894 Levene / 0,18 / 0,835	Method Null hypothesis: All variances are equal Alternative hypothesis: At least one variance is different Significance level: α = 0,05 Tests Method / Statistic / P-Value Multiple comparisons / — / 0,798 Levene / 0,19 / 0,829	Method Null hypothesis: All variances are equal Alternative hypothesis: At least one variance is different Significance level: α = 0,05 Tests Method / Statistic / P-Value Multiple comparisons / — / 0,546 Levene / 0,48 / 0,621
Analysis of Variance	Method Null hypothesis: All means are equal Alternative hypothesis: Not all means are equal Significance level: α = 0,05 Analysis of Variance Source / DF / Adj SS / Adj MS / F-Value / P-Value Factor / 2 / 5,92 / 2,961 / 0,01 / 0,985 Error / 27 / 5371,86 / 198,958 Total / 29 / 5377,78 Grouping information Using the Dunnett Method and 95% Confidence Factor / N / Mean / Grouping Y (control) / 10 / 63,71 / A Ye / 10 / 64,36 / A Ym / 10 / 63,27 / A	Method Null hypothesis: All means are equal Alternative hypothesis: Not all means are equal Significance level: α = 0,05 Analysis of Variance Source / DF / Adj SS / Adj MS / F-Value / P-Value Factor / 2 / 26,15 / 13,08 / 0,18 / 0,834 Error / 27 / 1933,49 / 71,61 Total / 29 / 1959,64 Grouping information Using the Dunnett Method and 95% Confidence Factor / N / Mean / Grouping Y (control) / 10 / 30,87 / A Ye / 10 / 33,09 / A Ym / 10 / 32,45 / A	Method Null hypothesis: All means are equal Alternative hypothesis: Not all means are equal Significance level: α = 0,05 Analysis of Variance Source / DF / Adj SS / Adj MS / F-Value / P-Value Factor / 2 / 0,0399 / 0,01996 / 0,03 / 0,973 Error / 27 / 19,9064 / 0,73727 Total / 29 / 19,9463 Grouping information Using the Dunnett Method and 95% Confidence Factor / N / Mean / Grouping Y (control) / 10 / 5,267 / A Ye / 10 / 5,331 / A Ym / 10 / 5,245 / A

Table 5. Mechanical characteristics of produced fibers and rachis materials

Material	Condition	Average maximum force, N	Average maximum tensile, MPA	Average maximum elongation, %
Chicken feather fiber	Unwashed	0.4023	133.13	5.202
	Hand cut	0.4191	144.00	5.168
	Machine cut	0.4146	137.27	5.121
Chicken feather rachis	Unwashed	63.71	3.087	5.267
	Hand cut	64.36	33.09	5.331
	Machine cut	63.27	32.45	5.245

4. CONCLUSION

Chicken feathers appear as a byproduct in chicken meat production, and most of them are found in production waste. Despite this, numerous studies have shown that chicken feathers have great industrial potential due to their valuable properties and low cost. One suggested industrial use of chicken feathers is the production of so-called feather fiber from feathers. Today, for the production of fibers from chicken feathers, comminuting machines are used that work according to different principles. In this case, the fibers are not separated from the rachis and a mixture of fibers with rachis is obtained, which is not a valuable product due to its heterogeneity. Therefore, this method of processing chicken feathers is not used on an industrial scale.

This study proposes an industrial method for the production of chicken feather fiber. According to this method, the fibrous part of the feather is cut from the rachis along its length, and thus two different materials are obtained: the feather fiber and the rachis. Each of these materials is homogeneous in composition and properties. Therefore, more suitable for industrial use as a more versatile and practical material than a feather. For separate the fibers from the rachis of chicken feathers a separator machine designed for a variety of purposes was used.

The mass ratio of the obtained materials has been investigated. It was revealed that using the investigated machine from chicken feathers it is possible to obtain 46.26% of pure feather fiber, 45.75% of feather rachis and 6.23% of feather flour. The remaining 1.76% of the feather is converted to waste in the form of a mixture of dust, fibers and rachis.

It was revealed that the weighted average length of the obtained fibers is 18.26 mm, and the weighted average diameter is 40.53 µm. The same parameters for the obtained rachis mass are 11.53 mm and 0.96 mm, respectively.

The structure and properties of the obtained fibers and pieces of rachis after processing chicken feathers by the proposed method have been investigated. As a result of analyzes, it was found that the properties of the fibers and rachis material obtained with this dispersing type machine did not change after the processing of the feather and are suitable for industrial use. It was also noted that the separating machine used allows the production of chicken feather fibers on an industrial scale, while separating the feather rachis. The productivity of the machine wherein is approximately 4.3 kg/hour.

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