Assessment of the biodegradability of feather raw material as a food substrate for ceratophagous insects

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Abstract: The article presents the results of a study to determine the degree of biodegradability of feather raw material as a food substrate for clothing moth caterpillars and brown carpet beetle larvae and shows that this indicator depends on the stage of development of ceratophagous insects. The paper aims to assess the degree of biodegradation of feather raw material as a food substrate for the caterpillars of clothing moths, Tineola bisselliella (Humm.), and the larvae of brown carpet beetles, Attagenus smirnovi Zhant. Once we used organoleptic examination to assess nutritional suitability of feather raw material for ceratophagous insects and analyzed its physical and chemical properties, we found that feather raw material is a favorable breeding ground for ceratophagous insects, as evidenced by its characteristics. As we compared the biodeterioration effect of clothing moth caterpillars and brown carpet beetles on untreated feather raw material, we found that samples affected by clothing moth caterpillars bore the most damage 28 days after the experiment began, i.e., 9.64%, while brown carpet beetle larvae affected 2.13% of the sample over that period, a direct consequence of the brown carpet beetle larvae development cycle. **Keywords**: feather raw material, ceratophagous insects, clothing moths, brown carpet beetle, keratinous raw material

1 Introduction

As a product of livestock and poultry farming, feather raw material is paramount to the national economy. Feather raw material is a by-product of poultry framing. Companies can make a fortune out of it if they use it efficiently, leaving no waste [1-7].

With the rise of large-scale poultry farms, it is now possible to obtain large amounts of feathers (about 5%–5.5% of the bird weight) once plumage is removed in the primary processing of poultry, and feather raw material is a valuable asset for light industry and feed production [3, 10].

This biological material is, however, highly vulnerable to microorganisms and ceratophagous insects as it features a significant amount of keratin [1, 2, 4, 5, 8, 11, 14, 15]. As keratin feeders, ceratophagous insects prey on animal-based materials as they feed on

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the natural protein—keratin—contained in them. That said, they can do biodeterioration damage even as larvae, so measures should be taken to protect raw materials from them [12, 13].

The moth caterpillar, Tineola bisselliella (Humm.), and the brown carpet beetle, Attagenus smirnovi Zhant, are classic examples of ceratophagous insects.

There are many reasons why they are a dangerous threat to fur, wool, leather, feather raw material, and all kinds of products made of it: their feeding behavior, high scleroprotein digestion and assimilation, which is a special kind of keratin, a constituent of hair and horns of mammals and bird feathers. Not only do they eat some of the material, but they also contaminate it with their by-products, making them accumulate many calories as larvae [5, 6, 9, 12, 13]. If we consider feather raw material as a source of nutrients for ceratophagous insects, due to the high content of protein and fatty substances in waterfowl feather, then feather raw material can serve as a food substrate for their larval forms.

The paper aims to assess the degree of biodegradation of feather raw material as a food substrate for the caterpillars of clothing moths, Tineola bisselliella (Humm.), and the larvae of brown carpet beetles, Attagenus smirnovi Zhant.

2 Research Materials and Methods

As the material for research, we chose fresh white graded feather raw material of a goose. In this paper, fresh white feather raw material has three or fewer flecks of color in an area of 20 dm^2.

We used gravimetric method to analyze moisture content (F.Y. Rachinsky, 1982). We used the manual method to determine the quantitative composition of feather raw material, strictly complying with the requirements of regulatory and technical documentation. We did organoleptic testing to detect odor after we heated the sample. To measure the mass fraction of protein, we applied the Kjeldahl method according to GOST 938.7-68 "Leather. Method for Determination of Nitrogen Content", a Russian national standard. We determined the content of fatty substances with a Soxhlet extractor, using only traditional methods of chemical analysis ("Determination of Mass Fraction of Fat of Feather Raw Material and Semi-finished Products" measurement procedure, OOO NPK Kariguz, 2001). We visually examined bacterial and chemical damage in the neocarmine sample (qualitative reaction) by the change in the color of the sample ("Determination of the Oxygen Index of Feather Raw Material and Semi-finished Products" measurement procedure, OOO NPK Kariguz, 2001) and the oxygen index, i.e., the amount of oxidised and soluble material present in the filtered aqueous extract of feather raw material ("Determination of the Oxygen Index of Feather Raw Material and Semi-finished Products" measurement procedure, OOO NPK Kariguz, 2001). We calculated the mass loss of the samples in accordance with the requirements of GOST 9.055-75 "Unified System of Protection against Corrosion and Ageing. Woollen Fabrics. Method of Laboratory Tests for Resistance to Moth Damage". We tested samples for resistance to clothing moth caterpillars depending on the contact time by keeping cages with samples and clothing moth caterpillars at 18±0.5°C and relative humidity of 65±8%. These are not the conditions where they develop and thrive; these are production conditions of storage. The experiment results were collected over 28 days, with days 7, 14, 21, and 28 as the end of each period under analysis, when we measured the average mass loss of samples (in %) in accordance with the requirements of GOST 9.055-75. We tested samples for resistance to brown carpet beetle larvae depending on the contact time, the same way we tested for resistance to clothing moth caterpillars [17]. Finally, to compile and analyse the statistics behind the experiment, we used Microsoft Office Excel 2010 for Windows.

3 Findings and Their Analysis

First, we analyzed the feather categories included in the sample under analysis. At 72x magnification of the Eichner microscope, the sample was found to contain 1% of duck feather in addition to firm goose feather and down.

Table 1 features the quantification findings for feather to down ratio in the feather raw material under research. This stage was paramount to the research, as we needed to compare the limit values of the components of feather raw material and their standard values.

Table 1. Mass Fractions of Feather Raw Material Components

Category of feather raw material	**Mass fraction, %**											
	Down components			**Feather components**								
	Down	**Immature down**	**Down feather**	**Medium feather**	**Fine feather**	**Neck feather**	**Immature feather**	**Broken fragments**	**Large feather**	**Underwing**	**Content of impurities**	**Fluff**
White feather raw material of a live goose	26.8	1.8	4.5	44.9	15.0	-	3.7	-	0.9	-	0.6	1.8
Requirements under GOST R 53397-2009	**at least 25.0**			**at least 66.0**		**-**	**5.0 max**	**-**	**1.0 max**	**-**	**3.0 max**	

As we can see from the findings, we identified the following feather raw material categories as we broke down the sample of goose feather from the processing plant: down, fine and medium feather, immature feather (about 4%), and large feather (about 1%). The feather raw material contained mineral impurities (sand, small pebbles) and had a natural odor typical of this type of raw material.

Safety is one of the main consumer properties; when it comes to feather raw material, we consider microbiological safety. That is why we used the neocarmine test (Figure 1), a qualitative reaction to biological and chemical damage, to detect chemical and bacteriological damage to feather raw material affected by chemical treatment products and microorganisms.

Fig. 1. Raw Materials Colored with Neocarmine

Neocarmine turned the samples greenish, a sign of bacterial contamination. No feather orange tips meant there was no chemical damage identified.

We used organoleptic examination along with physical and chemical parameter assessment; the findings can be found in Table 2.

Table 2. Quality Indicators of Feather Raw Material *(n=3)*

Indicator	Value	Regulation standard
Species	goose, 1% admixture of duck	-
Appearance	firm, mature, white	** Clean, firm, mature White—two or fewer flecks of color in an area of 20 dm^2*
Odor	natural	** natural*
Mass fraction of total protein, % of absolutely dry substance	92.58 ± 0.51	*no applicable regulations*
Fat, % of absolutely dry substance	2.56 ± 0.06	** 3% max*
Moisture, %	10.36 ± 0.18	** 13% max*
Oxygen Index, unit	25.50 ± 0.87	*** 20 max*
Bacterial contamination by neocarmine sample	yes	**** no applicable regulations*
Chemical damage by neocarmine sample	none	**** no applicable regulations*

Note: * GOST R 53397-2009; ** a measurement procedure of OOO NPK Kariguz, 2001; *** a measurement procedure of OOO NPK Kariguz M-01-2001

Raw material with the requirements of GOST R 53397-2009 in terms of appearance, color, and odor. The moisture was 10.36%, a standard for feather raw material. The fat was 2.56%, also typical for goose feather raw material, all within the GOST standard. The mass fraction of protein was 92.58%. There are no known regulations or standards applicable for this indicator. We, however, list it among the key indicators because it addresses the nutritional suitability of raw materials for ceratophagous insects.

We visually assessed its contamination and qualitatively determined the degree of its bacterial purity, a requirement for selecting the best storage conditions for feather raw material and describing its microbiological state. The oxygen index of 25.5 points to the initial stage of oxidative processes occurring in the feather raw material, with inevitable biodeterioration. Consequently, the raw material has bacterial contamination due to violations of collection and storage rules before processing and possibly high bioavailability.

The findings suggest that the raw materials from the batch analyzed are a favorable breeding ground for ceratophagous insects, as evidenced by their characteristics.

We used the chemical composition of the feather raw material to assess its food substrate potential for larval forms of ceratophagous insects. We did an in vitro study, where we assessed the biodeterioration of feather raw material due to clothing moth caterpillars and brown carpet beetle larvae; then we compared their biodeterioration effect.

We compiled the comparative findings from days 7, 14, 21, and 28 of the experiment; they can be found in Table 3.

Table 3. Biodeterioration of Feather Raw Material Samples Due to Larval Forms of Ceratophagous Insects

Biodeterioration agents	Indicators analyzed		
	Mass of initial sample, mg	Mass of sample after seeding, mg	Biodeterioration of feather raw material, %
Samples of feather raw material on day 7			
Clothing moth caterpillars (Tineola bisselliella)	99.67±1.24	97.33±1.24	2.01
Larvae of brown carpet beetle (Attagenus smirnovi Zhant)	98.67±0.45	98.07±0.63	0.73
Samples of feather raw material on day 14			
Clothing moth caterpillars (Tineola bisselliella)	99.03±0.77	94.70±0.56	4.00
Larvae of brown carpet beetle (Attagenus smirnovi Zhant)	98.00±0.82	97.37±0.99	1.35
Samples of feather raw material on day 21			
Clothing moth caterpillars (Tineola bisselliella)	100.00±0.71	92.97±0.97	7.03
Larvae of brown carpet beetle (Attagenus smirnovi Zhant)	100.67±0.38	98.53±0.44	2.79
Samples of feather raw material on day 28			
Clothing moth caterpillars (Tineola bisselliella)	100.33±0.90	91.00±0.93	9.64
Larvae of brown carpet beetle (Attagenus smirnovi Zhant)	99.00±0.71	95.90±0.33	2.13

At the end of the experiment, visual assessment revealed structural biodeterioration of the feather raw material vane on all samples, evidenced by increased fluff as felted down and, to a lesser extent, destroyed feather.

As we compared the biodeterioration effect of clothing moth caterpillars and brown carpet beetles on feather raw material, we found that samples affected by clothing moth caterpillars bore the most damage 28 days after the experiment began, i.e., 9.64%, while brown carpet beetle larvae affected 2.13% of the sample over that period, a consequence of the brown carpet beetle larvae development cycle.

Once we used organoleptic examination to assess the nutritional suitability of feather raw material for ceratophagous insects and analyzed its physical and chemical properties, we found that this keratinous raw material is a favorable breeding ground for ceratophagous insects, as evidenced by its characteristics.

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