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Original Article

Characterization of Chicken Feather Waste in Me Linh, Hanoi

Le Thi Hoang Oanh, Dang Thu Trang, Dang Thi Minh Phuong, Pham Van Quang, Luu Minh Loan, Nguyen Huu Huan, Tran Thi Hong*

VNU University of Science, 334 Nguyen Trai, Thanh Xuan, Hanoi, Vietnam

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Abstract: Chicken feather waste, a byproduct of the slaughtering process, may pollute the environment and pose a risk to human health. However, it is a potential source of organic nitrogen for agricultural application, such as animal feed and fertilizers. In Vietnam, Me Linh district, a large flower, vegetable and fruit growing area, is among the top of fertilizer use in Hanoi city. This study was carried out to assess the chicken feather waste in Me Linh district for further agricultural application. Information on the distribution, generation rate, and physicochemical (bulk density, pH, elements, and extractables) and biological properties (pathogens) of chicken feather waste was in focus. The measured elemental composition was typical for this kind of waste, showing its significant nitrogen content (TN ~ 12%), and high sulfur content (TS > 2%). Especially, chicken feather waste does not contain heavy metals, which are strictly regulated in QCVN 01-189/2019-BNNPTNT as for bio-organic fertilizer quality standards.

Keywords: Chicken feather waste, keratin, Me Linh, biological decomposition.

1. Introduction

In slaughterhouses, an average of 32.5–37.0% total weight of a chicken is wasted comprising of 57.37% feathers and skin; 20.35% intestine; 14.80% legs and other parts (< 1%) [1, 2]. Chicken feather accounts for about 5% - 10% of the total weight of the chicken [3, 4]. Population growth increases the demand for meat products, of which poultry meat accounts for 11%, and leads to an increase in feather waste [2]. According to a survey by the US Department of Agriculture, in 2020 about 100.5 million tons of meat were produced and as a result, more than 4.7 million tons of chicken feathers were generated around the world [5]. In Vietnam, in 2022, the total chicken herd was about 453 million, accounting for 81.43% of the total poultry herd; Industrial raised chicken meat is

* Corresponding author.
E-mail address: tranthihong@hus.edu.vn

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about 650 tons [6]. From 2018 to 2022, industrial raised chicken production accounts for 36-45% of the total chicken meat and has an average annual growth rate of 14.82% [6]. Chicken feather waste, if not properly treated, will cause problems of environmental sanitation, air and water pollution.

According to Costa et al., (2012), chicken feathers have volatile solids of up to 99 ± 1.4% [7]. Chicken feathers contain 92.0 ± 0.48% crude protein, including about 82.8 ± 0.51% keratin, hence it is very rich in N, with a content of up to ~14% [8]. Therefore, it can be used as animal feed, nutritious and environmentally friendly organic fertilizer [1]. Chicken feather is also a potential raw material in the production of low-cost adsorbents, polymers, and composites [9-11]. Exploiting the potential value of chicken feather waste not only helps reduce waste but also brings about additional income for farmers.

Me Linh is a suburban district and a supplier of agricultural products for the capital Hanoi of Vietnam. Notably, Me Linh is also a large flower, vegetable and fruit growing area in the North, with agricultural land accounting for 57% of the total natural land area of 14,000 hectares [12]. Dong Cao Dam Van Dua General Service Cooperative alone, with over 900 member households, has provided the Hanoi market with about 20% of all kinds of fruits and vegetables [12]. In addition to small household farming units, in 2019, statistics showed that the whole district had 37 crop farms and 1752 livestock farms [13]. Me Linh district is among the top users of fertilizers and pesticides in Hanoi; In 2019, the amount of pesticide accounted for 1/6 of the total pesticide used in Hanoi [14]. Aware of the advantages and disadvantages of using fertilizers and pesticides, the district advocates promoting the reuse and processing of organic waste and agricultural by-products as/into environmentally friendly raw materials and fuel [15].

Therefore, this study was conducted to survey the current status of chicken feather waste in Me Linh district (Hanoi) as a scientific basis for proposing biological treatment solutions to produce nitrogen-rich fertilizer that meets the environmental treatment needs, while also serving agricultural activities in this locality.

2. Investigation Methods

2.1. Field Survey

Data on chicken slaughter was collected at the People's Committee of Me Linh District (Economic Department and Environmental Resources Department) [16] to serve as a basis for selecting a number of facilities for surveying on the situation of generation, treatment and characteristics of chicken feather waste (Table 1). All registered slaughterhouses in Me Linh district (6 in total, denoted thereafter as from No.1 to No.6), according to the information collected, were interviewed about slaughter capacity, slaughter method, generated amount, treatment methods and personal observation of characteristics of chicken feather waste.

At each slaughterhouse, one collective chicken feather waste sample was obtained for analysis of chemical and physical properties in early morning (2-3 am) on September 7-8, 2023 (27-35 ^{o}C, 54% cloud, 71% humidity, 6 km/h SSE wind). Only feather wastes from industrial rised white chickens were collected regarding the purpose of fertilizer production, hence there were in total 6 samples from 5 different slaughterhouses (2 samples for slaughterhouse No.1, the largest one). The sample was taken 30 minutes after being removed from chicken bodies and drained in the plastic basket with pore size of 5 mm. This sample was then preserved in zipped bag in ice box for 5 hours during the transportation to the lab for analysis.

The amount of chicken feather waste, generated per each chicken, was measured by weighing at a slaughterhouse to determine or verify the interview data.

2.2. Characterization of Chicken Feather Waste

Physicochemical properties of chicken feather waste (water content, pH, bulk density,

total elements, available phosphorus, available potassium, extractable ions, fecal coliforms, *Salmonella*, etc.) were analyzed based on the standards cited in QCVN 01-189/2019-BNNPTNT or equivalent standard methods [17]. Water content was determined based on weight loss at 70^{o}C in oven (TCVN 9297: 2012, Memmert UN160 m). The dried sample was then grounded by a medical grinder for analysis of elements and substance components. pH was measured in 1:5 ratio soluble extract on wet weight basis using pH meter (TCVN 5979: 2007, M200 easy, Easysense pH 33, InPro 3030/120, Mettler Toledo). Bulk density was measured as wet weight of chicken feather waste per unit volume (five repetitions) (TCVN 13793: 2023**)**. Sample was filled in a plastic bucket with full volume of 5 L. To ensure a full accupancy rate, the bucket was lifted up to a height of 6 cm and let being fallen vertically 5 times. Total carbon (TC) was calculated based on the ash content (A) of sample according to equation [18] (Eq. (1)):

$$\%TC = (100 - \%A)/1.8 \quad (1)$$

in which:

TC: total carbon;

A: ash content;

1.8: the factor correcting for the fact that the weight loss is not linearly equivalent to the amount of carbon material;

A of organic material is obtained by heating 2 g sample in a capped ceramic cup at 600 ^{o}C for 5 hours in a furnace. A is determined by the proportion of solid after heating process in dry weight of the initial sample (Eq. (2)).

$$\%A = (m_{600}-m_0)/(m_{105}-m_0)*100 \quad (2)$$

where

m_0: Weight of heating cup without the sample;

m_{105}: Sample weight after drying at 105 ^{o}C;

m_{600}: Sample weight after heating at 600 ^{o}C.

Total nitrogen (TN), total phosphorus (TP), total potassium (TK), and total sulfur (TS) were measured on acid digested solutions using regular -Kjeldahl method (TCVN 8557: 2010, K19/16 Gerhardt SOXTHERM), a spectrophotometer (TCVN 8563:2010, 134190 Cecil spectrophotometer), a flame photometer (TCVN 8560: 2018, 61068 Jenway), and gravimetric method (TCVN 9296: 2012, CWF 12/36 Carbolite chamber furnace), respectively. Metal contents (e.g., As, Pb, Hg, Cu, Zn, and Cd) were measured on king water digested sample using inductively coupled plasma optical emission spectroscopy (TCVN 9556-2-2013, ICP-OES iCAP PRO X). Available phosphorus ($P_{available}$) was measured on acid extraction solutions using spectrophotometric method (TCVN 8559: 2010, 134190 Cecil spectrophotometer). Extractable NH_4^+, PO_4^{3-}, SO_4^{2-} and NO_3^- were measured in 1:30 ratio extract based on dried weight basis using phenolnate method (APHA 4500 – NH_3F, HACH 3900), ascorbic method (APHA 4500 PE, HACH 3900), turbidimetric method (APHA 4500- SO_4^{2-}E, HACH 3900), and sulfosalicylic acid method (TCVN 6180: 1996, HACH 3900), respectively. Microbial analyses were carried out on wet sample within 12 hours of storage in refrigerator at 4 ^{o}C. Fecal coliforms were quantifed using most probable number techniques (TCVN6846:2007). *Salmonella* was detected using horizontal method (TCVN 10780-1:2017).

Measurements, if not described otherwise, were undertaken in triplicated. Average and standard deviation values were obtained by using Excel 2021.

3. Results and Discussion

3.1. Status Quo of Chicken Feather Waste Generation

According to the Agricultural Service Center, there are in total 6 slaughterhouses registed with the local authority in Me Linh in March 2023 (Table 1) [16]. Of the 6 facilities listed, 5 had slaughter capacity of less than 50 chickens/day and the remaining facility had a slaughter capacity of 600 chickens/day. The facility with the highest slaughter capacity had a business registration, a food safety certificate

and a registered slaughter control code. It had an area of 1000 m^2, whereas the areas of the remaining facilities were all ≤ 100 m^2. All facilities employ manual slaughter method and have wastewater treatment systems except the last facility.

Table 1. Information collected from Me Linh District People's Committee about slaughterhouses

Slaughterhouse	Registration name	Address	Capacity (chickens/ day)	Slaughter method	Area (m^2)	Wastewater treatment system
1	Le Van Thuy	Thanh Van, Thanh Lam	600	Manual	1000	Available
2	Nguyen Van Hong	Group 4, Chi Dong town	35	Manual	40	Available
3	Nguyen Van Hoa	Group 1, Chi Dong town	30	Manual	30	Available
4	Nguyen Van Tuc	Yen Bai, Tu Lap	50	Manual	100	Available
5	Nguyen Van Phuc	Yen Bai, Tu Lap	50	Manual	120	Available
6	Le Thi Hai Yen	Yen Nhan, Tien Phong	50	Manual	100	Not available

Table 2. Chicken feather waste and its treatment in registered slaughterhouses

Slaughter house	**Registration name**	**Type of chicken**	**Capacity (chickens/ day)**	**Slaughter method**	**Average weight of unslaughtered chicken (kg/chicken)**	**Chicken feather waste generation rate (kg wet weight/chicken)**	**Treatment method**
1	Le Van Thuy	Industrial white chicken	1000	Semi-automatic	3.2 – 3.25	na	Sold
2	Nguyen Van Hong	Industrial white chicken + Vietnamese chicken	30	Manual	3.3	> 0.3	Collected in bags and waste in handcart for household waste collection
3	Nguyen Van Hoa	Industrial white chicken + Vietnamese chicken	20	Manual	3.5 – 4.0	0.2 (0.1 kg dry weight/chicken)	Collected in bags and waste in handcart for household waste collection
4	Nguyen Van Tuc	Vietnamese chicken	5-7	Manual	-	0.17	Collected in bags and waste in handcart for household waste collection; sold for fertilizer production
5	Nguyen Van Phuc	No longer active in slaughter work					
6	Le Thi Hai Yen	Industrial white chicken	100	Manual	3.5 - 4.5	0.25	Collected in sack to waste in waste storage location in commune within the day; Sold; composting using effective microorganisms but with bad odor
7	Vuong Thi Minh	Industrial white chicken	200	Manual	3.5	0.55 (0.3 kg dry weight/chicken)	

Field surveys in Me Linh on August 9, 2023 showed that facilities registering for slaughter licenses were mostly households which had slaughter capacity larger than 30 chickens/day. In addition to registered facilities, many slaughterhouses still exist and operate with smaller capacity and manual slaughter method in local markets. Moreover, one unregistered slaughterhouse was discovered (Slaughterhouse 7), that had capacity of 200 chickens/day. At registered facilities, there are changes such as increasing or decreasing of the slaughter capacity, shifting from purely manual to semi-automatic slaughter. Characteristics of chicken feather waste as observed by owners of slaughterhouses are listed in Table 2.

When slaughtering chickens, the entrails, skin, blood and claws are sold as fish food. Chicken feather waste is handled by the slaughterhouse, but the main form is to collect them in bags and put them in handcart for household waste collection. In large-scale slaughterhouses, chicken feathers are immediately sold to chicken feather dealers. The amount of feather waste produced per chicken is usually between 0.1 kg and 0.3 kg wet weight. Chicken feather waste is discharged in the mixture with feces and blood, causing a very unpleasant odor and requiring space to contain. Some slaughterhouses used to try effective microorganisms to treat chicken feather waste. The resulting fertilizer was very good for plants, but the problem of bad odor is a challenge of this solution when implemented in a family's living area. To utilize chicken feather waste, one slaughterhouse applies it as soil cover in the crop field.

By directly measuring on 10 chickens at a slaughterhouse (wet feather) and at the laboratory (drained feather), the average weight of feather waste per chicken was found of 267 ± 33 g for wet feather and 234 ± 33 g for drained feather, accounting for 7.38% and 5.88% of unslaughtered chicken weight, respectively (Table 3). The rate of chicken feather waste is lower than those reported by da Silva [3] and Salminen & Rintala due to higher chicken weight [4].

3.2. Characteristics of Chicken Feather Waste

3.2.1. Physicochemical Parameters

- pH and water content.

pH and water content of chicken feather waste were measured for 10 chickens at a slaughterhouse (wet feather) and at the laboratory (drained feather) after 6 hour-storing in plastic basket with pore size of 5 mm (Table 3).

Table 3. pH and water content of chicken feather waste

Chicken No.	Weight (kg)	Wet feather			Drained feather		
		pH	Water content (%)	Weight (g/chicken)	pH	Water content (%)	Weight (g/chicken)
1	4.1	6.20	80.34 ± 0.12	369.3	7.20	74.91 ± 0.15	289.33
2	4.2	6.00	75.57 ± 0.15	257.4	7.00	72.42 ± 0.17	227.97
3	4.3	6.00	75.34 ± 0.22	280.0	6.50	72.11 ± 0.25	247.59
4	4.1	6.00	81.64 ± 0.14	280.1	6.00	72.80 ± 0.21	189.11
5	3.6	6.00	74.56 ± 0.27	279.0	7.00	70.77 ± 0.31	242.86
6	3.8	6.00	76.88 ± 0.23	293.4	6.50	72.51 ± 0.28	246.78
7	3.9	6.00	76.61 ± 0.23	273.1	6.50	72.68 ± 0.27	233.88
8	3.9	6.20	76.74 ± 0.14	327.6	6.50	70.46 ± 0.18	257.92
9	4.0	6.20	77.16 ± 0.14	309.3	6.50	69.62 ± 0.19	232.55
10	4.0	6.20	75.91 ± 0.23	268.8	7.20	62.56 ± 0.36	172.98
Average	3.99 ± 0.19	6.08 ± 0.10	77.07 ± 2.15	267.10 ± 33.40	6.69 ± 0.37	71.09 ± 3.21	234.05 ± 33.06

The pH of wet feather ranged from 6.00 to 6.20, lower than the pH of drained feather, which ranged from 6.00 to 7.20. This shows that chicken feather waste tends to become more alkaline when stored because it is decomposed and produce NH_3. Wet feather had an average water content of 77.07% ± 2.15; significantly higher than the average water content of drained feather, which was 71.09% ± 3.21. The water content of chicken feather waste is higher than feather (69,34%) due to its mixture with blood [19].

- Bulk density

The average bulk density of chicken feather waste at slaughterhouses was 373.55 g/L with a standard deviation of 36.19 g/L (Table 4). Note that the slaughterhouse No.7 in Table 4 is a new one found during the field investigation in Me Linh district. This variance reflects the differences in sample collection: the longer the collection time is from the slaughter time, the lower the bulk density due to the long draining time. The slaughter method also affects the bulk density of chicken feather waste. In the semi-automatic slaughter method, chicken feathers are shot from the feather plucking device and gathered on the floor, hence there are more favorable conditions for dewatering, leading to a bulk density that tends to be lower than chicken feather waste obtained from manual slaughter. The bulk density of chicken feather waste is higher than that of feather (300 g/L) due to the mixture of feather with blood, skin, and claw nail of chicken, which have higher bulk density [19]. Bulk density of chicken feather waste is similar to that of vegetable waste, higher than those of water hyacinth, water thyme, sawdust and dry leaves, while lower than those of cow dung, sewage sludge, and industrial sludge [20].

Table 4. Bulk density of chicken feather waste in slaughterhouses (g/L)

Slaughterhouse / Replication	1	1	2	3	6	7
1	322.90	342.20	301.80	420.20	400.22	481.74
2	414.00	353.20	356.48	361.76	359.40	424.26
3	275.14	322.14	360.52	438.68	374.00	502.20
4	348.40	271.66	339.32	369.32	346.60	405.60
5	349.08	406.60	357.36	397.54	356.60	447.72
Average	341.90 ± 50.27	339.16 ± 48.99	343.10 ± 24.52	397.50 ± 32.72	367.36 ± 20.82	452.30 ± 39.82

- Elemental composition

TP content ranged from 467.18 mg/kg to 694.23 mg/kg, TK from 320.19 mg/kg to 475.00 mg/kg (Table 5). The average TN content was about 12%. TC had a fairly uniform value for all samples at ~54%. TS ranged from 1.48% to 2.76%. The C/N ratio ranged from 4.43 to 5.07. The amount of TN and TS in chicken feather waste were quite large, leading to the generation of odor-causing gases such as NH_3 and H_2S during the biological decomposition process.

The TC and TN content of chicken feather waste were in the range with those in previous studies with corresponding values of 48.98% - 64.47% and 10.00 - 15.29%, respectively [7, 8, 21, 22]. The TS content in previous studies was in line with this study with values of 2.07% and 2.64%, respectively [21, 22]. In comparison to most of organic wastes (household, agricultural, industrial waste and sludge), chicken feather waste has a highest and significant TN [19, 20].

High TN and TS content of chicken feather waste is attributed to its protein nature (92% dry mass) with keratin as the major component (82.8% dry mass) [7]. Keratin is a fibrous protein, comprised of different amino acids, of which cysteine (>7% feather protein) has a high number of disulfide bonds [23, 24]. TP and TK of chicken feather waste were much higher than those found in chicken manure [25], however lower than those in cow dung, groundnut stover, potato plant, soybean, mustard stover [26].

Table 5. Elemental composition of chicken feather waste

Slaughterhouse	Replication	TP (mg/kg)	TK (mg/kg)	TN (%)	TC (%)	TS (%)	C/N ratio
1	1	694.23	334.26	12.28	54.43	1.52	4.43
	2				55.14	2.76	4.49
1	1	683.31	376.48	12.28	54.92	2.01	4.47
	2				54.92	2.01	4.47
2	1	489.01	475.00	10.78	54.64	1.94	5.07
	2				54.71	2.32	5.07
3	1	589.44	397.59	12.23	54.80	1.60	4.48
	2				55.01	2.42	4.50
6	1	541.41	387.04	12.19	54.77	1.64	4.49
	2				54.59	1.48	4.48
7	1	467.18	320.19	12.22	54.54	1.88	4.46
	2				54.89	2.26	4.49

Table 6. Metal content of chicken feather waste

Metal \ Slaughterhouse		1	1	2	3	6	7	QCVN 01-189: 2019/ BNNPTNT
Al	mg/kg	0	87.83	0	0	457.17	0	-
As	mg/kg	nd	nd	nd	nd	nd	nd	≤ 10 mg/kg
Sn	mg/kg	0.33	0	0	1.33	0	0	-
Hg	mg/kg	nd	nd	nd	nd	nd	nd	≤ 2 mg/kg
Zn	mg/kg	17.67	26.33	19.50	18.50	31.50	23.33	-
Pb	mg/kg	0	0	0	0	0	0	≤ 200 mg/kg
Cd	mg/kg	0	0	0	0	0	0	≤ 5 mg/kg
Ni	mg/kg	0.17	0.50	0	0	0.17	1.00	-
Fe	mg/kg	36.00	79.33	9.00	17.33	35.50	38.33	-
Si	mg/kg	24.50	28.00	37.33	18.67	69.00	30.67	-
Mn	mg/kg	6.50	13.67	7.00	5.17	11.00	11.33	-
Mg	mg/kg	145.33	163.33	162.33	134.00	201.17	156.00	-
Cr	mg/kg	3.83	3.33	0.67	2.17	2.50	1.67	-
Ca	mg/kg	211.33	235.83	102.17	162.17	273.33	112.50	-
Na	mg/kg	373.00	519.50	586.83	383.67	491.33	318.33	-
Cu, Ag	mg/kg	0	0	0	0	0	0	-
Se, Te, Sb, Co, W	mg/kg	nd	nd	nd	nd	nd	nd	-

nd: not detected
Detection limits: Al 0.05 µg/L, As 1.8 µg/L, Cd 0.12 µg/L, Co 0.28 µg/L, Cr 0.18 µg/L, Cu 0.67 µg/L, Hg 1.1 µg/L, Mo 0.9 µg/L, Ni 0.3 µg/L, Pb 0.8 µg/L, Sb 2.1 µg/L, Se 2.4 µg/L, Sn 1.1 µg/L, Tl 2 µg/L

The metals from high to low content are Na > Ca > Mg > Al > Si > Fe > Zn > Mn > Cr > Sn > Ni, respectively (Table 6). Ag, Cu, Cd, Pb, As, Hg, Se, Te, Sb, Co, W were not detected. According to regulations on limiting factors including As, Cd, Hg, Pb for bio-organic fertilizers by QCVN 01-189: 2019/BNNPTNT, chicken feather waste is an ideal material

because they do not contain any of these metals. Nurdiawati's research also did not detect Cd, As, Hg, Se, Co in chicken feather samples, Cu content was close to 0, Ca was 5 times higher while Na and Fe had values equivalent to the values obtained in this study [21].

- Extractable parameters

The ratio of extractable ions including NO_3^- - N, NH_4^+ - N, PO_4^{3-} - P and SO_4^{2-} - S compared to the dry weight of chicken feather waste ranged in 0.001% - 0.004%, 0.004% - 0.007%, 0.042% - 0.063% and 0.016% - 0.043%, respectively. Available phosphorus ($P_{available}$) ranged from 0.053% to 0.103% with an average value of 0.080% ± 0.017% dw. The extractable content accounted for a very small part compared to the total content of TN, TP and TS because the process of decomposing chicken feathers has not yet taken place and the elements exist in insoluble protein form (Table 7).

NO_3^- - N of chicken feather waste is higher than that of food waste, dairy manure and sewage sludge but lower than that of rice straw, and matured composts from the mixture of rice straw and the priveous wastes [27]. NH_4^+ - N is lower than that of all abovementioned wastes [27].

Table 7. Extractable and plant-available parameters

Slaughterhouse	Extractable parameters				Plant-available parameters
	NO_3^- - N (% dw)	NH_4^+ - N (% dw)	PO_4^{3-} - P (% dw)	SO_4^{2-} - S (% dw)	$P_{available}$ (% dw)
1	0.004 ± 0.0007	0.007 ± 0.0003	0.056 ± 0.0004	0.042 ± 0.0009	0.084 ± 0.0150
1	0.001 ± 0.0001	0.006 ± 0.0001	0.063 ± 0.0003	0.043 ± 0.0001	0.103 ± 0.0009
2	0.001 ± 0.0002	0.007 ± 0.0012	0.048 ± 0.0010	0.021 ± 0.0004	0.082 ± 0.0089
3	0.001 ± 0.0005	0.004 ± 0.0010	0.047 ± 0.0032	0.026 ± 0.00001	0.085 ± 0.0072
6	0.001 ± 0.00008	0.006 ± 0.0004	0.046 ± 0.0005	0.016 ± 0.00006	0.070 ± 0.0014
7	0.001 ± 0.0007	0.005 ± 0.0006	0.042 ± 0.0006	0.031 ± 0.00007	0.053 ± 0.0114
Average	0.001 ± 0.001	0.006 ± 0.001	0.050 ± 0.007	0.030 ± 0.01	0.080 ± 0.0171

Table 8. Fecal coliforms and Salmonella in chicken feather waste

Slaughterhouse	1	1	2	3	6	7
Fecal coliforms MPN/g	1.1×10^6	3.6×10^6	4.4×10^7	1.1×10^9	1.2×10^7	3.1×10^6
Salmonella	-	-	-	-	-	-
- : not detected						

3.2.2. Biological Parameters

Fecal coliforms density in chicken feather waste samples were determined immediately after taking the samples to the laboratory, using the method of determining the most probable number (MPN/g). The presence of *Salmonella* was also quantified at the same time (Table 8).

Salmonella was not detected in all chicken feather waste samples. Fecal coliforms were found with density from 1.1×10^6 to 1.1×10^9 MPN/g. Fecal coliforms in chicken feather waste collected from semi-automatic slaughter tends to be lower than that obtained from manual slaughter. In semi-automatic slaughter process, the volume of water used is larger and its temperature is rather stable; Hence, more fecal coliforms are died off during the removal of feathers.

Fecal coliforms and *Salmonella* normally account for >20% pathogens found in chicken feather waste [28]. The level of these microorganisms depends on different factors. *Salmonella* could be found at very low levels (0.6-3.1%) or relatively high levels such as 30% in chicken products [2].

4. Conclusions

According to the survey in Me Linh district, chicken feather waste was generated at small household-scale slaughterhouses with slaughter capacity of about 30 chickens/day including industrial white chickens and Vietnamese chickens. There was only one slaughterhouse with a large slaughter capacity of 1000 chickens/day that had a business license and food safety certification. The average amount of chicken feather waste produced from industrial white chickens was 267 ± 33 g for wet feathers and 234 ± 33 g for drained feathers, accounting for 7.38% and 5.88% of unslaughtered chicken weight, respectively. The average bulk density of chicken feather waste at slaughterhouses was 357.80 ± 24.92 g. The pH of wet feathers ranges from 6.00 to 6.20, lower than the pH of drained feathers ranged from 6.00 to 7.20. Wet feather had an average water content of 77.07 ± 2.15%; significantly higher than the average water content of drained feathers, which was 71.04 ± 3.21%. TC and TN of chicken feather waste were quite uniform for 6 samples collected at different slaughterhouses with average values of ~54% and ~12%, respectively. TP content ranged from 467.18 mg/kg to 694.23 mg/kg, TK from 320.19 mg/kg to 475.00 mg/kg, and TS ranged from 1.48% to 2.76%, respectively. The metals from high to low content were Na > Ca > Mg > Al > Si > Fe > Zn > Mn > Cr > Sn > Ni, respectively. Ag, Cu, Cd, Pb, As, Hg, Se, Te, Sb, Co, W were not detected. The ratio of extractable ions including NO_3^- - N, NH_4^+ - N, PO_4^{3-} - P and SO_4^{2-} - S compared to the dry weight of chicken feather waste ranged from 0.001% - 0.004%, 0.004% - 0.007%, 0.042% - 0.063% and 0.016% - 0.043%, respectively. $P_{available}$ content ranged from 0.053% to 0.103% with an average value of 0.080% ± 0.017% dw. *Salmonella* was not detected in all chicken feather samples. Fecal coliform were found from 1,1 x 10^6 to 1,1 x 10^9 MPN/g wet chicken feather waste. Fecal coliform in chicken feather waste obtained by semi-automatic slaughter tends to be lower than that of manual slaughter. The chemical composition such as TC, TN, TS, and metals is characteristic and quite similar to previous studies on chicken feather waste. However, information on distribution, generation rate, bulk density, pH, extractables, etc. are information that is rarely found for this type of waste on a global scale and serves as the basis for proposing appropriate treatment measures towards bio-economy and circular economy.

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References

[1] B. B. Adhikari, M. Chae, D. C. Bressler, Utilization of Slaughterhouse Waste in Value-added Applications: Recent Advances in the Development of Wood Adhesives, Polymers, Vol. 10, 2018, pp. 176, https://doi.org/10.3390/polym10020176.

[2] V. Mozhiarasi, T. S. Natarajan, Slaughterhouse and Poultry Wastes: Management Practices, Feedstocks for Renewable Energy Production, and Recovery of Value Added Products, Biomass Conv. Bioref., Vol. 15, 2025, pp. 1705-1728, https://doi.org/10.1007/s13399-022-02352-0.

[3] R. R. D. Silva, Keratinases as an Alternative Method Designed to Solve Keratin Disposal on The Environment: Its Relevance on Agricultural and Environmental Chemistry, J Agric Food Chem, Vol. 66, 2018, pp. 7219-7221, https://doi.org/10.1021/acs.jafc.8b03152.

[4] E. Salminen, J. Rintala, Anaerobic Digestion of Organic Solid Poultry Slaughterhouse Waste – A Review, Bioresource Technology, Vol. 83, 2002, pp. 13-26, https://doi.org/10.1016/S0960-8524(01)00199-7.

[5] J. Qiu, C. Wilkens, K. Barrett, A. S. Meyer, Microbial Enzymes Catalyzing Keratin Degradation: Classifcation, Structure, Function, Biotechnol Adv, Vol. 44, 2020, pp. 107607, https://doi.org/10.1016/j.biotechadv.2020.107607.

[6] Livestock Vietnam, Overview of Poultry Livestock in Period 2018-2023 (P1), Journal of Livestock

Vietnam, 2023, https://nhachannuoi.vn/tong-quan-ve-nganh-chan-nuoi-gia-cam-giai-doan-2018-2022-p1/ (accessed on: July 25th, 2024) (in Vietnamese).

[7] J. C. Costa, S. G. Barbosa, D. Z. Sousa, Effects of Pre-treatment and Bioaugmentation Strategies on the Anaerobic Digestion of Chicken Feathers, Bioresour Technol, Vol. 120, 2012, pp. 114-119, https://doi.org/10.1016/j.biortech.2012.06.047.

[8] Y. Xia, D. I. Massé, T. A. McAllister, Anaerobic Digestion of Chicken Feather with Swine Manure or Slaughterhouse Sludge for Biogas Production, Waste Manage, Vol. 32, No. 3, 2012, pp. 404-409, https://doi.org/10.1016/j.wasman.2011.10.024.

[9] S. A. Asheh, F. Banat, D. A. Rousan, Beneficial Reuse of Chicken Feathers in Removal of Heavy Metals from Wastewater, J Clean Prod, Vol. 11, 2003, pp. 321-326, https://doi.org/10.1016/S0959-6526(02)00045-8.

[10] C. A. S. Moreno, E. C. González, M. Z. S. Leos, Use and Treatment of Chicken Feathers as A Natural Adsorbent for The Removal of Copper in Aqueous Solution, J Environ Health Sci Engineer, Vol. 19, No. 1, 2021, pp 707-720, https://doi.org/10.1007/s40201-021-00639-4.

[11] N. Reddy, L. Chen, Y. Yang, Biothermoplastics from Hydrolyzed and Citric Acid Crosslinked Chicken Feathers, Mater Sci Eng C Mater Biol Appl, Vol. 33, No. 3, 2013, pp. 1203-1208, https://doi.org/10.1016/j.msec.2012.12.011.

[12] L. Hang, M. Linh District Develops Effectively Specialized Production Areas, Capital Labour Newspaper, 2023, https://laodongthudo.vn/huyen-me-linh-phat-trien-co-hieu-qua-cac-vung-san-xuat-chuyen-canh-162228.html. (accessed on: July 25th, 2024) (in Vietnamese).

[13] General Statistic Office, 2024, https://www.gso.gov.vn/px-web2/?pxid=V0650&theze=N%C3%B4ng%2C%20l%C3%A2m%20nghi%E1%BB%87p%20v%C3%A0%20th%E1%BB%A7y%20s%E1%BA%A3n (accessed on: July 25th, 2024) (in Vietnamese).

[14] N. Nga, Changing the Habit of Using Fertilizers and Pesticides, Capital Women Electronic Newspater, 2020, https://baophunuthudo.vn/kinh-te-xa-hoi/thay-doi-thoi-quen-su-dung-phan-bon-thuoc-tru-sau-52783.html (accessed on: July 25th, 2024) (in Vietnamese).

[15] N. Thu, Me Linh: Promote Reuse and Processing Organic Waste, Agricultural By-products into Environmentally Friendly Raw Materials and Fuel, Me Linh Distric Electronic Information Portal, 2022, https://melinh.hanoi.gov.vn/me-linh-thuc-day-tai-su-dung-che-bien-chat-thai-huu-co-phu-pham-nong-nghiep-thanh-nguyen-lieu-nhien-lieu-than-thien-voi-moi-truong-173221006150228869.htm (accessed on: July 25th, 2024) (in Vietnamese).

[16] Agricultural Service Center, People's Committee of Me Linh District, List of Animal Slaughter Facilities and Points in March, 2023 (in Vietnamese).

[17] QCVN 01-189: 2019/BNNPTNT, National Technical Regulation on Fertilizer Quality (in Vietnamese).

[18] R. T. Haug, The Practical Handbook of Compost Engineering, Taylor & Fransis, New York, 1993.

[19] R. Avidov, V. S. Varma, I. Saadi, A. Hanan, I. Yoselevich, A. Lublin, L. Chen, Y. Laor, Physical and Chemical Indicators of Transformation of Poutry Carcass Parts and Broiler Litter During Short Term Thermophilic Composting, Waste Manag, Vol. 119, 2021, pp. 202-214, https://doi.org/10.1016/j.wasman.2020.09.040.

[20] M. S. Jain, S. Paul, A. S. Kalamdhad, Kinetics and Physics During Composting of Various Organic Wastes: Statistical Approach to Interpret Compost Application Feasibility, J Clean Prod, Vol. 255, 2020, pp. 120324, https://doi.org/10.1016/j.jclepro.2020.120324.

[21] A. Nurdiawati, B. Nakhshiniev, I. N. Zaini, N. Saidov, F. Takahashi, K. Yoshikawa, Characterization of Potential Liquid Fertilizers Obtained by Hydrothermal Treatment of Chicken Feathers. Environmental Progress & Sustainable Energy,Vol. 37, No. 1, 2017, 8pp, https://doi.org/10.1002/ep.12688.

[22] T. Tesfaye, B. Sithole, D. Ramjugernath, V. Chunilall, Valorisation of Chicken Feathers: Characterisation of Chemical Properties, Waste Manag,Vol. 68, 2017, pp. 626-635, https://doi.org/10.1016/j.wasman.2017.06.050.

[23] H. L. Stilborn, E. T. Moran, F. M. Gous, M. D. Harrison, Effect of Age on Feather Amino Acid Content in Two Broiler Strain Crosses and Sexes. J. Appl. Poultry Res., Vol. 6, 1997, pp. 205-209, https://doi.org/10.1093/japr/6.2.205.

[24] T. K. Kowalska, J. Bohacz, Biodegradation of Keratin Waste: Theory and Practical Aspects. Waste Manag. Vol. 31, No. 8, 2011, pp. 689-1701, https://doi.org/10.1016/j.wasman.2011.03.024.

[25] G. A. Ogunwande, J. A. Osunade, K. O. Adekalu, L. A. O. Ogunjimi, Nitrogen Loss in Chicken Litter Compost as Affected by Carbon to Nitrogen Ratio and Turning Frequency, Bioresour Technol,

Vol. 99, 2008, pp. 7495-7503, http://doi.org/10.1016/j.biortech.2008.02.020.

[26] T. Karak, I. Sonar, R. K. Paul, S. Das, R. K. Boruah, A. K. Dutta, D. K. Das, Composting of Cow Dung and Crop Eesidues Using Termite Mounds as Bulking Agent, Bioresour Technol, Vol. 169, 2014, pp. 731-741, https://doi.org/10.1016/j.biortech.2014.06.110.

[27] S. P. Wang, X. X. Li, Z. Y. Sun, W. L. Shuai, Z. Y. Xia, C. Y. Xie, M. Gou, Y. Q. Tang, Evaluation of Physicochemical Properties, Bacterial Community, and Product Fertility During Rice Straw Composting Supplemented with Different Nitrogen-rich Wastes, Bioresour Technol, Vol. 369, 2023, pp. 128462, https://doi.org/10.1016/j.biortech.2022.128462.

[28] A. N. Mohammed, An Alternative Approach for Controlling Bacterial Pathogens in Liquid and Solid Poultry Waste Using Calcium Hypochlorite $Ca(OCl)_2$ Disinfectant-based Silver Nanoparticles, Scientific Reports, Vol. 12, 2022, pp. 19733, https://www.nature.com/articles/s41598-022-24203-8 (accessed on: July 25th, 2024).