American Journal of Animal and Veterinary Sciences

Research Article

Adding Duckweed (*Lemna minor*) to Local Duck Diet: Determined Based on the Performance and Heavy Metal Concentration in their Meat

Syamsuhaidi, Uhud Abdullah, Dwi Kusuma Purnamasari and Ryan Aryadin Putra

Department of Animal Nutrition and Feed Science, Faculty of Animal Science, University of Mataram, Indonesia

Article history
Received: 14-12-2024
Revised: 06-02-2025
Accepted: 11-03-2025

Corresponding Author:
Syamsuhaidi
Department of Animal Nutrition and Feed Science, Faculty of Animal Science, University of Mataram, Indonesia
Email: syamsuhaidi@unram.ac.id

Abstract: An experiment was conducted to determine whether adding duckweed fertilized with bioslurry to the diet corresponds to duck performance and heavy metal concentration in their meat. The study was designed using a completely randomized design. The treatments were different levels of adding duckweed as a diet component, as follows: Basal feed (control, no duckweed, TC), basal feed +2.5% duckweed (TL1), basal feed +5% duckweed (TL2), basal feed +7.5% duckweed (TL3), and basal feed +10% duckweed (TL4). Each treatment diet was provided twice daily for the ducks aged 3 to 12 weeks during the experiment. The results showed that duckweed is a promising alternative protein source for ducks, with a crude protein content of 16.9%. Duckling adding duckweed to their diet did not affect feed consumption, average daily weight gain, and feed conversion, but significant effects were recorded on the concentrations of all variable heavy metals deposited in their meat ($p<0.05$). In conclusion, a diet prepared with the addition of duckweed up to 10% in the total ration did not result in any adverse effects on the productivity performance of ducks, and it should be noted that all samples of duck meat were found to contain a relatively high concentration of Cu, Pb, Ni, Cr, and Hg with some concentrations exceeded quality standards. Further research is required to investigate the various access points of heavy metal accumulation besides feed exposure and the underlying mechanisms behind this phenomenon.

Keywords: Aquatic Feed, Duckweed, Duck Meat, Heavy Metal, Bioaccumulation

Introduction

Globally, ducks are one of the livestock species that play an important role in producing meat and eggs, which are essential animal protein sources for humans. This condition contributes to the growing demand for duck meat and eggs. Farmers must respond by intensifying their duck production to meet this challenge. Similarly, ducks are one of Indonesia's principal livestock commodities for meat and egg production. However, their rearing is predominantly concentrated among small-scale farmers who utilize improvised rearing management practices, with inadequate consideration for ensuring optimal nutritional status and productivity. Those conditions are primarily due to limited feed availability and sufficient nutrient quality. Consequently, identifying and introducing unconventional local feed ingredients in duck feed has emerged as a significant challenge (El-Katcha *et al.*, 2021). One of the most promising aquatic plants for utilization as animal feed is the *Lemna minor* (Duckweed).

Duckweeds are floating aquatic macroscopic plants. They belong to the family *Lemnaceae*, a monocotyledonous flowering plant group (Khellaf and Zerdaoui, 2010). As macrophytes, they have been observed to exhibit a greater capacity for accumulating heavy metals in plant water bodies (Amare *et al.*, 2018), with these metals subsequently transported to shoots and other plant tissues (Goyal *et al.*, 2020). Furthermore, duckweed employed fluoranthene (Zezulka *et al.*, 2013) and pharmaceutical residues in water (Bianchi *et al.*, 2020; Maldonado *et al.*, 2022) before its utilization as an alternative feed ingredient. On the other hand, duckweed is high in nutrients, especially crude protein, making it a promising source of protein-rich biomass for animal feed. It also represents a viable solution to the problem of land scarcity currently facing animal feed production.

Several studies have already proven that this plant is suitable for feeding various livestock species, such as poultry (Demann *et al.*, 2022; Shammout & Zakaria, 2015), ruminants (Tanuwiria & Mushawwir, 2020; Omotoso *et al.*, 2023; Gule *et al.*, 2023), and duck (Indarsih & Tamsil, 2012; Men *et al.*, 2002). However, the author's research was deficient in data on the accumulation of heavy metals in meat due to the use of duckweed as feed. The toxicity effects of these metals can result in chronic poisoning, which has the potential to cause the death of the livestock in question, as well as of humans who consume the products of that livestock.

Meat consumption is becoming an increasingly prominent feature of global diets (Ihedioha *et al.*, 2014). It serves as a principal source of nourishment, providing essential nutrients such as protein, minerals, vitamins, fats, and other vital micronutrients for optimal bodily function (Han *et al.*, 2022). The quality and composition of the meat depend on genetic and environmental factors, as well as on the diet of the birds and the level of protein in the feed (Kuzniacka *et al.*, 2014). Although meat is a valuable source of nutrients, it can also serve as a conduit for humans to be exposed to heavy metals.

The accumulation of toxic metals from anthropogenic pollution represents a significant health risk to consumers (Ihedioha *et al.*, 2014). Therefore, the critical point in ensuring meat quality is its nutritional content and safety, which must be free from substances that can endanger consumer's health. As has been previously stated, feeding ducks feed containing heavy metal compounds will result in the deposition of these heavy metals in the meat produced. Therefore, this study was conducted to determine duck performance and whether heavy metals contained in duckweed were deposited in the meat of ducks fed several levels of duckweed fertilized with bio-slurry.

Materials and Methods

Ethical Clearance

The study was conducted ethically, ensuring the ducks' well-being and humane treatment. During the study, the ducks were provided with adequate housing. The conditions included space, ventilation, clean water and a balanced diet. The husbandry practices followed standards to minimize stress and ensure health. Humane slaughter methods have been implemented to minimize pain and suffering. Such procedures are performed by trained personnel who follow best practices in animal welfare.

The study was conducted in accordance with institutional and international ethical guidelines on animal welfare and was reviewed and approved by the Ethics Committee of the Faculty of Animal Science, University of Mataram (approval number 1607/FapetUN/ETIK/2023).

Location

The study was conducted at the Teaching Farm Research Station, Faculty of Animal Science, University of Mataram. The ambient temperature varied from 26 to $29^{O}C$, with a humidity range of 60 to 75%.

Birds and Housing

The study employed 75 DODs of local Alabio duck (*Anas platyrhynchos Borneo*) with average weights ranging from 37-40 g (±1.43 g) as experimental objects. The ducks were reared in a brooder with standard commercial feed for rearing until they reached 21 days of age. Fifteen experimental cages were prepared in 1x2 m size. Each cage is equipped with food and drink containers, and heating comes from a 25-watt incandescent lamp. After a 21-day rearing period, the experimental animals were divided into 5 groups according to the number of treatments to be applied.

The standard commercial feed used is produced by PT. JAPFA Comfeed Indonesia, with ingredients consisting of soybean meal (SBM), Meat Bone Meal (MBM), Corn Gluten Meal (CGM), Distiller's Dried Grains with Solubles (DDGS), poultry by-product meal (PBM), Palm oil, and affixes by amino acid, bicarbonate, vitamins, and enzymes. The nutritional composition of these commercial feeds is shown in Table (1).

Table 1: Nutrient composition of commercial concentrates used as duckling reached 21 days of age

Chemical composition	Content
Dry matter	Maks. 89%
Ash	Maks. 35%
Crude protein	Min. 34%
Crude fiber	Maks. 8.5%
Ether extract	Min. 2%
Calcium	9 - 12%
Phosphorus	Min. 0.5%
Phytase enzyme	≥400 FTU/kg
Urea	Not detected
Aflatoxin total	Maks. 40 µg/kg
Lysine	Min. 1.70%
Methionine	Min. 0.80%
Methionine + Sistin	Min. 1.30%
Threonine	Min. 1.10%
Tryptophan	0.34%

Preparation and Growing of Duckweed

A total of 3 units of 4x8 m ponds equipped with floating nets were prepared for growing duckweed. About 100 g of duckweed seeds were distributed among the ponds, with 5% bio-slurry fertilizer added per volume of water. The duckweed was then selected for approximately 24 h before being harvested and repeated daily. The harvested fresh duckweed was then provided to the ducks following the treatment level.

In order to conduct a chemical analysis, approximately 200 g of fresh duckweed from each pond was harvested and subsequently dried in an oven maintained at a temperature of 60°C until the weight remained constant. Subsequently, the dried duckweed samples were weighed and milled in order to analyze their nutrient and heavy metal content.

Chemical Composition Analysis

About 25 g of duckweed meal was sampled to analyze its nutrient composition comprehensively, including Dry Matter (DM), Crude Protein (CP), Crude Fibre (CF) and its fractions, Ether Extract (EE), Calcium (Ca), Phosphorus (P), and GE content. Additionally, the samples were analyzed for their heavy metal content, specifically the presence of copper (Cu), cadmium (Cd), lead (Pb), nickel (Ni), chromium (Cr), and mercury (Hg). The chemical composition of duckweed was analyzed per the AOAC (2012) method, while the fibre fraction (ADF and NDF) was tested based on the Van Soest *et al.* (1991) method. The heavy metal content was analyzed using an Atomic Absorption Spectrophotometer (AAS) based on the Butcher (2005) method.

The identical methodology employed for analyzing heavy metal concentrations in duckweed was subsequently applied to examining duck meat at the termination of the experimental period. A total of 50 g of duck meat (a mix of drumstick and breast meat) was dried in an oven at 60°C until the weight remained constant. It was then milled, weighed, and placed in free-metal bags to be transported to the subsequent analysis step. The meat samples were prepared in the Animal Nutrition and Feed Science laboratory, Faculty of Animal Science, University of Mataram. The heavy metal analysis was conducted in the Analytical Chemistry Laboratory, Faculty of Mathematics and Natural Science, University of Mataram, Indonesia.

Growing Birds and Research Management

Starter periods. About 75 DODs were maintained in box cages with 3x3 m dimensions until they were two weeks old. The ducks were provided with concentrate feed at a rate of 70 g/head/day. The cages were equipped with feeding and drinking facilities. Following an acclimation period of two weeks, the ducks were transferred to litter cages with a 4x4 m size. During this phase, the ducks were gradually adapted to the treatment feed until they reached 3 weeks of age.

Growing periods. The rearing period, which commenced at the time of hatching and continued until the ducks reached 12 weeks of age, is hereafter referred to as the grower period. Ducks aged 12 weeks are placed in 15 cage units, each with 2x3 m dimensions and holding five ducks. Each unit is equipped with feed and water containers on occasion. The amount of feed was divided into two periods: the first, from 3 to 8 weeks, entailed the administration of 95 g/day, while the second, from 8 to 12 weeks, entailed the administration of 145 g/day. The feed was provided twice daily, in the morning and evening. The drinking water was provided ad libitum.

Feed and Feeding

Ground corn, bran, concentrate, and Crude Palm Oil (CPO) were the feed ingredients used in the current experiment. The concentrate employed as a constituent component of the ration in the present study was a commercial concentrate for broiler ducks, branded Comfeed KIP3. Its ingredients included SBM, MBM, CGM, CPO, premix, essential amino acids, and essential minerals. The chemical composition of the feed ingredients is presented in Table (2).

Table 2: Chemical composition of feedstuff

Nutrient content[1]	Feedstuff			
	Ground corn	Rice bran	Cons[2]	CPO
DM (%)	87.86	90.54	94.22	100.00
CP (%)	8.60	11.50	34.65	0.00
CF (%)	3.50	15.50	6.12	0.00
EE (%)	2.40	7.00	3.77	100
Ca (%)	0.02	0.07	3.00	0.00
P (%)	0.27	1.40	1.50	0.00
ME (kcal/kg)	3400	1890	2729	7000

[1]DM: Dry Matter; CP: Crude Protein; CF: Crude Fiber; EE: Ether Extract; Ca: Calcium; P: Phosphorus; ME: Metabolizable Energy;
[2]Cons: The Comfeed KIP3 commercial concentrate for broiler ducks contains SBM, MBM, CGM, CPO, premix, amino acids, and minerals

Table 3: Ingredient and nutrient composition of experimental duck diets

Ingredient, %	Feeding treatment[2]				
	TC	TL1	TL2	TL3	TL4
Ground corn	35	35	32.5	30	30
Rice bran	33	30	30	30	27.5
Concentrate	30	30	30	30	30
Duckweed	0	2.5	5	7.5	10
Crude palm oil	2	2.5	2.5	2.5	2.5
Total	100	100	100	100	100
Nutrient composition[1]					
ME, kcal/kg	2772	2816	2796	2775	2793
CP, %	17.20	17.28	17.49	17.69	17.83
CF, %	8.18	8.08	8.36	8.64	8.62
EE, %	6.28	6.61	6.59	6.57	6.43
Ca, %	0.93	0.95	0.97	0.98	1.00
P, %	1.01	0.98	0.98	0.98	0.96

[1]DM: Dry Matter; Cp: Crude Protein; CF: Crude Fiber; EE: Ether Extract; Ca: Calcium; P: Phosphorus; ME: Metabolizable Energy
[2]TC: Control, without the inclusion of duckweed; TLI: 2.5% inclusion of duckweed; TL2: 5% inclusion of duckweed; TL3: 7.5% inclusion of duckweed: TL4: 10% inclusion of duckweed

DOI: 10.3844/ajavsp.2025.86.96

All rations in the current experimental were set to isocaloric and iso-proteinous by adding duckweed and formulated with a target energy of 2700 kcal/kg and crude protein of 17% (Table 3).

Experimental Design and Data Analysis

The study was designed using a completely randomized design. A total of 75 ducks were assigned to five feed treatments, differentiated by duckweed level. The treatments were as follows: TC = basal feed (control, no duckweed); TL1 = basal feed + 2.5% duckweed; TL2 = basal feed + 5% duckweed; TL3 = basal feed + 7.5% duckweed; and TL4 = basal feed + 10% duckweed. Each treatment was applied three times, with each replicate comprising five ducks.

The experimental data were analyzed using the General Linear Model (GLM) procedure of IBM SPSS version 20, with a significance set at 5%. The figure was generated using Microsoft Excel version 2019.

Results and Discussion

Nutrient Composition and Heavy Metal Concentration of Duckweed

Duckweed is an aquatic plant that can grow well without fertilizer, but when given the appropriate dose of fertilizer, it will be able to increase its dry matter production. Dry matter production in duckweed typically reduces following the decline in plant growth rate, which can be caused by several stresses such as nutrient deficiencies or imbalances, toxins, and the pH of the growth medium. The current experiment revealed that the nutrient content of duckweed was 7.95% (DM), 80.1% (OM), 16.9% (CP), 14.7 (CF), 45.4% (ADF), 55.3% (NDF), 1.5% (EE), 0.77% (Ca), 0.45% (P), and 3301 kcal/kg (GE), respectively (Table 4). The DM content of our results is slightly lower than that reported by Miltko *et al.* (2024) on lesser duckweed (*Lemna minor L.*) in the natural environment, which produced 9.81%. However, our results showed higher crude protein and fibre content. Mwale and Gwaze (2013) reported that duckweed has a high protein content, reaching 9-20% in nutrient-poor media and 24-41% in nutrient-rich media.

Our current results demonstrated that the concentrations of heavy metals such as copper (Cu), cadmium (Cd), lead (Pb), nickel (Ni), chromium (Cr), and mercury (Hg) in duckweed were 12.2, 0.60, 13.9, 2.46, 0.73, and 0.21 mg/kg, respectively (Table 4). The uptake of heavy metals by duckweed has also been documented by Miltko *et al.* (2024), with a total uptake of cadmium and lead of 0.368 mg/100 g crude ash. In a previous study, other researchers also investigated heavy metal levels in several duckweed species of Wolffia. The authors demonstrated that the Pb concentration ranged from 13 to 1020 µg/kg freeze-dried weight (Appenroth *et al.*, 2018).

The capacity of duckweed to absorb both macronutrients and micronutrients and significant quantities of heavy metals from aqueous environments can be attributed to its phytoremediation capabilities (Amare *et al.*, 2018; Appenroth *et al.*, 2018; Bianchi *et al.*, 2020; Zezulka *et al.*, 2013; Ziegler *et al.*, 2017). It is evident that this capacity renders duckweed a highly efficacious means of mitigating the repercussions of facultative sewage ponds in the context of wastewater treatment (Singh *et al.*, 2011; Goyal *et al.*, 2020). Heavy metals absorbed by plant roots are transported to shoots and other plant tissues (Jadia & Fulekar, 2009). Therefore, it is crucial to ascertain the concentration of heavy metals taken up before considering their use as livestock feed.

The nutrient content of a plant is determined by the environment in which it grows. The environment provides the nutrients needed to grow, which are then converted into the nutrients present in the plant material through photosynthesis. When their nutritional and environmental needs are met, duckweed plants grow fast and thrive long (Lasfar *et al.*, 2007). Furthermore, Leng *et al.* (1995) stated that duckweed thrives in waters with a steady supply of nutrients, which it gets from decaying organic material. The results of the analysis of nutrient composition and the concentration of heavy metals in duckweed fertilizer with bioslurry are presented in Table (4).

Table 4: Chemical composition and heavy metal content of duckweed (Lemna sp.) fertilizer with bioslurry

Items	Value
Nutrient composition	
Dry matter, %	7.95
Organic matter, %	80.1
Crude protein, %	16.9
Crude fiber, %	14.7
Acid detergent fiber, %	45.4
Neutral detergent fibre, %	55.3
Ether extract, %	1.70
Calcium, %	0.77
Phosphorus, %	0.45
Gross energy, kcal/kg	3301
Beta-carotene, mg/kg	238
Heavy metal concentration (mg/kg)	
Cooper (Cu)	12.2
Cadmium (Cd)	0.60
Lead (Pb)	13.9
Nickel (Ni)	2.46
Chromium (Cr)	0.73
Mercury (Hg)	0.21

Feed Consumption, Average Daily Gain, and Feed Conversion

The findings revealed that the feed consumption, daily body weight gain, and feed conversion values of the ducks treated with duckweed in their diets exhibited no discernible response to the basal diet (control diet). The feed consumption observed in our results ranged from 113.2 to 126.8 g/d. Furthermore, Baghban-Kanani *et al.* (2023) have also reported that adding 10-15% duckweed to replace wheat and soybean meal in the ration does not affect feed consumption in laying hens. Adding 10% and 15% duckweed to the diet resulted in feed consumption of 108.5 and 107.9 g/d, respectively. These values were not different from the control treatment, which showed a mean feed consumption of 108.5 g/d. However, the feed consumption observed in our study was slightly higher than expected, likely attributable to the different breeds of poultry involved, given their varying tolerance to crude fibre. Nevertheless, the addition of duckweed up to 10% as a component of the diet did not result in any observable limitation in feed consumption, contrary to the findings of Leung *et al.* (2018), who suggested that high fibre content in poultry rations may negatively impact on palatability, intake, and digestibility.

According to the study, there were indications of increased feed consumption when duckweed was included in the duckling feed formulation, particularly in the TL3 treatment, compared to the control treatment. However, this increase did not significantly affect the daily body weight gain of the experimental ducks. The average daily gain ranged from 19.9 to 21.6 g/day (Table 5). These findings indicate that the incorporation of duckweed into the diet does not exert a deleterious effect on growth or feed consumption. Sulaiman and Irawan (2020) stated that including duckweed in the ration ingredients can reduce the use of corn by up to 5% of the total ration, providing economic benefits. Previous studies have also shown that duckweed presents an alternative protein source for animal feed, leading to increased interest in its use (Baek *et al.*, 2021).

The term Feed Conversion Ratio (FCR) describes the relationship between the quantity of feed consumed and the resulting change in body weight, which can illustrate the production efficiency level. Our current results demonstrated that all rations incorporating duckweed exhibited no discernible difference in feed conversion values compared to the control treatment. Another study by Supriatman *et al.* (2017) demonstrated that the feed conversion of male local ducks fed a commercial diet and the addition of *Etlingera elatior* flower extract resulted in FCR values ranging from 4.97 to 5.30. Nevertheless, a lower feed conversion value for male local ducks has been previously documented by Arifah *et al.* (2013), with a range of 3.03 to 4.49. The discrepancies in the outcomes of feed conversion values are contingent upon many variables, including genetics, body size, sex, age, and dietary intake. Even suboptimal management practices, such as the quantity and nutritional composition of the feed provided, can influence these values.

Duckweed contains nutrients supporting livestock growth; however, its crude fibre content may limit nutrient consumption. Nevertheless, its potential as an alternative feed ingredient remains promising. The findings of the Research by Adriani *et al.* (2016) indicated that incorporating 4.5% duckweed meal into broiler rations increased final body weight, carcass weight, carcass percentage, and abdominal fat. Putrayasa *et al.* (2024) proposed adding 5% of duckweed fermented with Saccharomyces cerevisiae in another report. Previously, Akter *et al.* (2011) demonstrated that the pigmentation of egg yolks increased with increasing levels of duckweed in the diet, with the optimum yolk colouration observed at a 150 g/kg ratio.

Table 5: Feed consumption, average daily gain, and feed conversion of duck fed with duckweed fertilizer with bioslurry

Treatment[1]	Items		
	Feed consumption (g/d)	Average daily gain (g/d)	Feed conversion
TC	119.8	19.9	5.86
TL1	123.4	20.9	5.77
TL2	121.8	20.7	5.76
TL3	127.0	21.7	5.72
TL4	125.3	20.7	5.92
s.e.m[2]	3.256	0.451	0.172
P-value	0.761	0.881	0.973

[1]*TC: ration control without the inclusion of duckweed; TLI: ration with 2.5% inclusion of duckweed; TL2: ration with 5% inclusion of duckweed: TL3: ration with 7.5% inclusion of duckweed: TL4: ration with 10% inclusion of duckweed*
[2]*s.e.m: standard error of the mean*

Accumulation of Heavy Metal Content in Duck Meat

Heavy metals in foodstuffs, such as meat, can be attributed to their mobility and propensity for bioaccumulation in water, plants, and soil (Scutarașu and Trincă, 2023). In addition, contamination of the feed may also be a source of contamination. Duckweed species can accumulate significant quantities of heavy metals, potentially impacting human and livestock normal development and health (Miltko *et al.*, 2024). Heavy metals are required in varying amounts for the metabolism of living organisms (Singh *et al.*, 2011), and the toxicity of these substances is contingent upon their concentration exceeding the recommended level (Rehman *et al.*, 2021).The present study demonstrated that the presence of heavy metals in the meat of the ducks was indicative of systemic contamination from untraceable sources. This finding was supported by the overall concentration of heavy metals detected in the TC treatment, which was administered without the addition of duckweed to the diet. Figure (1) presented heavy metal concentration in the duck meat experiment.

DOI: 10.3844/ajavsp.2025.86.96

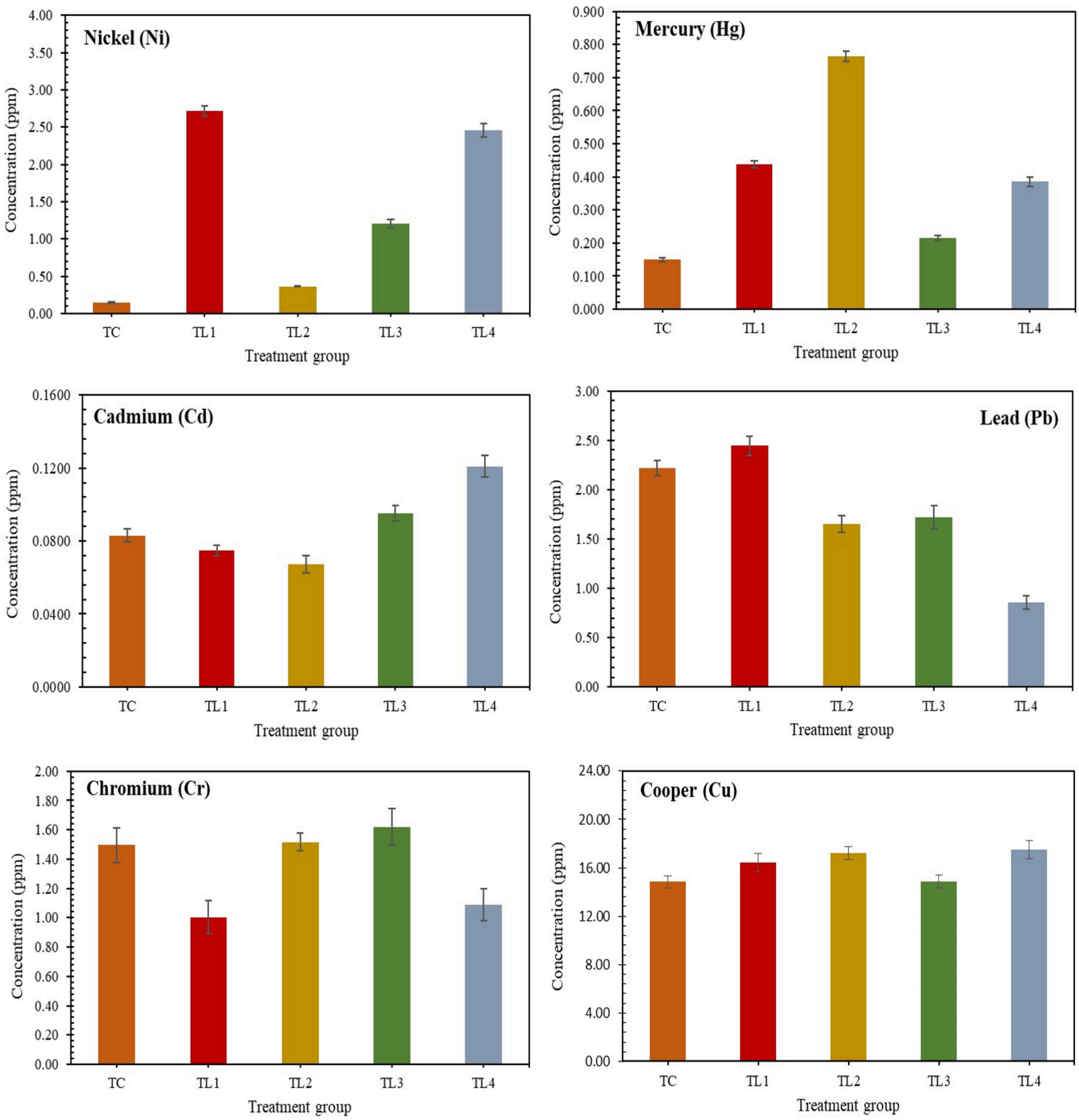

Fig. 1: The concentration of heavy metal (mean ± Se) in duck meat fed duckweed fertilizer with bioslurry

The Cu concentration in the duck meat of the study exhibited notable discrepancies across the various group treatments ($p<0.05$), as evidenced by the findings of our investigation. The lowest concentration of copper was observed in the Control Treatment (TC), with a concentration of 14.8±0.53 mg/kg, while the highest concentration was observed in the TL2 group, with a value of 17.2±0.55 mg/kg (Figure 1). The Cu concentration obtained in this study was higher than that reported by Susanti *et al.* (2020), who observed a Cu concentration of duck meat across several regions in Central Java with an average concentration of 0.86 mg/kg. The elevated bioaccumulation of Cu metal in the duck meat in our experiment was attributable to the high concentration of Cu in the duckweed used as feed (Table 4).

Our observation of the Cd concentration of duck meat showed differences between treatment groups with a range of Cd concentrations from 0.07±0.003 to 0.12±0.006 mg/kg ($p<0.05$). The highest Cd concentration was found in the 10% duckweed treatment (TL4) (Figure 1). The range of Cd content in duck meat is at least still below the threshold for Indonesia standards set by Standar Nasional Indonesia (2009), which is 0.10-0.27 mg/kg, and lower than the Cd concentration of duck meat collected from traditional markets, which is 0.44 mg/kg (Widayanti and Widwiastuti, 2018), the authors further explained that the presence of residues in poultry meat indicates the possibility of cadmium contamination from feed, drinking water and soil. The concentration of Cd in poultry will usually increase over time because it is bioaccumulative, so poultry can be used as an indicator of heavy metal pollution in the environment and humans as consumers.

The Pb content in the duck meat was found to decrease with the addition of duckweed ($p<0.05$) (Figure 1). The highest Pb concentration was observed in the TL1 treatment (2.44±0.10 mg/kg), followed by the TC (2.22±0.08 mg/kg), TL3 (1.72±0.12 mg/kg), and TL2 treatment (1.65±0.08 mg/kg). In contrast, the lowest concentration was recorded in the TL4 treatment (0.85±0.07 mg/kg) (p<<.05). The decline in Pb metal concentration could be indicative of a metabolic response in the ducks aimed at averting a heavy metal poisoning incident. In general, the detoxification mechanisms employed by birds and other animals encompass the uptake of heavy metals by proteins such as metallothionein, which bind and neutralize metals before excreting them from the body, thereby potentially mitigating their toxic effects (Suljević *et al.*, 2020). Furthermore, the presence of intestinal bacteria has been demonstrated to play a pivotal role in the reduction of Pb levels. As Susanti *et al.* (2022) reported that the decline in Pb metal content by 50.82% in duck meat is closely associated with the increase in bacteria from the Peptococcaceae family, which functions as a biological agent for the remediation of Pb within the duck's digestive tract.

The Pb concentration of duck meat in the present study exceeded the quality standards set out by the (FAO, 2017) of 0.1 mg/kg. In contrast, the meat produced in the TL4 treatment was recorded as still under the determined quality standard. The accumulation of Pb in livestock can result from several sources, including ingesting contaminated feed, consuming groundwater, and ingesting soil. As reported by Wang *et al.* (2013), some animal feeds in China were found to contain Pb at levels exceeding 10 mg/kg. As poultry feed is derived from plant material, contamination of the plants will inevitably result in contamination of the feed (Susanti *et al.*, 2020).

The toxic metal Nickel (Ni) can enter the livestock body, primarily through ingesting contaminated feedstuffs, resulting in various toxicological effects. In our current study, the concentration of Ni in TC, TL1, TL2, TL3, and TL4 treatments was 0.15±0.01 mg/kg, 2.71±0.07, 0.37±0.01, 1.21±0.06, and 2.46±0.09 mg/kg, respectively ($p<0.05$), with the highest concentration being obtained in TL1 treatment and the lowest in TC treatment. The elevated Ni concentration in duck meat remains a well-documented phenomenon, as evidenced by Chowdhury and Alam (2024). In their study, the authors evaluated the Ni concentration in duck meat sourced from the Noakhali district of Bangladesh, with a reported concentration of 5.09 mg/kg. Previously, other researchers have reported Ni concentrations of 1.55 mg/kg in quail meat (Darwish *et al.*, 2018) and 1.19 µg g-1 in chicken meat (Abduljalee *et al.*, 2012).

Similarly, a pattern was observed in Cr concentrations that were not aligned with feed consumption. The findings revealed no significant difference in Cr concentrations among TC, TL2, and TL3 treatments (1.50±0.12 mg/kg, 1.52±0.06 mg/kg, and 1.62±0.12 mg/kg, respectively). However, there were notable differences when compared to the Cr concentrations observed in the TL1 (1.00±0.11 mg/kg) and TL4 treatments (1.09±0.11 mg/kg) ($p<0.05$). The Cr concentration in duck meat observed in the present study was lower than that Abduljalee *et al.* (2012) reported for chicken and quail meat collected in Selangor, Malaysia. However, the maximum permissible concentration of chromium contaminants in food is 1.00 mg/kg of fresh meat (Han *et al.*, 2022).

The mercury (Hg) concentration in duck meat ranged from 0.15±0.007 to 0.76±0.015 mg/kg. The meat from the TL2 treatment exhibited the highest Hg concentration compared to other treatment groups ($p<0.05$). The elevated concentration of Hg in TL2, in comparison with the control (TC), resulted in a substantial increase in bioaccumulation ratio exceeding 510%. Conversely, Hg accumulation exhibited a decline in bioaccumulation percentage in TL3 and TL4 treatments, with reductions of 28.1% and 50.5%, respectively. This decline in bioaccumulation may be attributable to the bioremediation capacity of ducks, which employs physiological mechanisms to circumvent the deleterious effects of these heavy metals. Susanti *et al.* (2022) in their study also reported that the concentration of Hg was reduced by more than 20% of the metal that entered the duck's body due to the metal content in the meat. The Hg concentration in the current experiment was considerably higher than the threshold recommended by the FAO (2017), which is 0.1 mg/kg. Other authors have reported a lower Hg concentration in chicken meat. For instance, Liang *et al.* (2019) found a concentration of 0.012 mg/kg, while Han *et al.* (2022) reported a concentration of approximately 0.004 mg/kg in fresh meat in China. However, it is acknowledged that the discrepancy in concentrations indicates that the levels of this metal in animals vary by geographical area, potentially due to the influence of diverse contaminant sources.

The precise reason for the absence of a correlation between heavy metal deposition and retention in duck meat with feed consumption remains unclear. We understand that an increase in feed consumption should increase heavy metal intake. It is hypothesized that the observed variation in heavy metal concentrations in the duck meat may be attributed to the contribution of various contaminants, including from feedstuff and groundwater drinking, or even the use of litter bedding mixed with cage soil, all of which accumulate and degrade in the duck muscle. Furthermore, it is hypothesized that the contamination of feed ingredients within the ration may also have occurred during the upstream-to-downstream process, contributing to the high bioaccumulation observed in the meat of the current experiment ducks. This assertion is corroborated by Susanti *et al.* (2022), who reported that levels of heavy metal contamination in duck meat are associated with pollutants present in water and feed, with the most significant contamination being attributed to Hg and Cu metals.

Duckweed is a valuable source of nutrients that can complement livestock diets. Unlike maize or soya, duckweed is not a genetically modified crop, making it an excellent choice for livestock nutrition. However, it is essential to continuously monitor the concentration of antinutritional components of heavy metals in duckweed cultures (Miltko *et al.*, 2024). It is acknowledged that the present study has certain limitations, namely the omission of testing for all potential sources of heavy metal contamination. The results obtained demonstrate that the presence of heavy metals in duck meat is indicative of systemic contamination from untraceable sources. This finding is supported by the overall concentration of heavy metals detected in the TC treatment, which was fed without the addition of duckweed to the diet. It is evident that further Research is necessary to investigate the various access points of heavy metal accumulation besides feed exposure, as well as the underlying mechanisms behind this phenomenon.

Conclusion

Incorporating duckweed as a dietary component at a level of up to 10% of the total ration did not result in any adverse effects on the productivity performance of ducks. All samples of duck meat (including those not treated with duckweed) were found to contain elevated levels of heavy metals, namely Cu, Pb, Ni, Cr, and Hg, with some concentrations exceeding quality standards, indicating food safety and health concerns of the ducks themselves when considering the inclusion of duckweed in their diets. Further research is required to investigate the various access points of heavy metal accumulation besides feed exposure and the underlying mechanisms behind this phenomenon.

Acknowledgment

We would like to express our gratitude to Millenium Challenge Accounts Indonesia (MCA Indonesia), HIVOS Indonesia, and the Faculty of Animal Science University of Mataram for fully funding this Research.

Author's Contributions

Syamsuhaidi: Designed, analyzed the data, and prepared the first manuscript.

Dwi Kusuma Purnamasari, Uhud Abdullah and Ryan Aryadin Putra: Conducted the Research and prepared data tabulation.

Ryan Aryadin Putra and Syamsuhaidi: The laboratory analyzed and reviewed the manuscript.

Ethics

This article is original, has no ethical issues, and was not published elsewhere. The corresponding author confirmed that all authors have read and approved the final manuscript.

Conflict of Interest

The authors declared there was no competing interest during the Research and during the writing of the manuscripts.

References

Abduljalee, S. A., Shuhaimi-o, M., & Babji, A. (2012). Assessment of Trace Metals Contents in Chicken (Gallus Gallus Domesticus) and Quail (Coturnix Coturnix Japonica) Tissues from Selangor (Malaysia). *Journal of Environmental Science and Technology*, *5*(6), 441-451. https://doi.org/10.3923/jest.2012.441.451

Adriani, Y., Jehemat, A., Abdullah, U., & Syamsuhaidi. (2016). Lemna sp. sebagai Pakan Ternak Organik. *Sebagai Pakan Ternak Organik. Konsorsium Hivos*. https://www.rumahenergi.org/files/Lemna-as-organic-stock-fodder.pdf

Akter, M., Chowdhury, S. D., Akter, Y., & Khatun, M. A. (2011). Effect of Duckweed (Lemna Minor) Meal in the Diet of Laying Hen and their Performance. *Bangladesh Research Publications Journal*, *5*(3), 252-261.

Amare, E., Kebede, F., & Mulat, W. (2018). Wastewater Treatment by Lemna Mand Azolla Ffiliculoides in Tropical Semi-Arid Regions of Ethiopia. *Ecological Engineering*, *120*, 464-473. https://doi.org/10.1016/j.ecoleng.2018.07.005

A.O.A.C. (2012). *Association of Official Analytical Chemists International (19th)*.

Appenroth, K.-J., Sree, K. S., Bog, M., Ecker, J., Seeliger, C., Böhm, V., Lorkowski, S., Sommer, K., Vetter, W., Tolzin-Banasch, K., Kirmse, R., Leiterer, M., Dawczynski, C., Liebisch, G., & Jahreis, G. (2018). Nutritional Value of the Duckweed Species of the Genus Wolffia (Lemnaceae) as Human Food. *Frontiers in Chemistry*, *6*, 483. https://doi.org/10.3389/fchem.2018.00483

Arifah, N., & Ismoyowati , N. I. (2013). Tingkat Pertumbuhan Dan Konversi Pakan Pada Berbagai Itik Lokal Jantan (Anas Plathyrhinchos) Dan Itik Manila Jantan (Cairrina Moschata). *Jurnal Ilmiah Peternakan*, *1*(2), 718-725.

Baek, G., Saeed, M., & Choi, H.-K. (2021). Duckweeds: Their Utilization, Metabolites and Cultivation. *Applied Biological Chemistry*, *64*(1), 1-15. https://doi.org/10.1186/s13765-021-00644-z

Baghban-Kanani, P., Oteri, M., Hosseintabar-Ghasemabad, B., Azimi-Youvalari, S., Di Rosa, A. R., Chiofalo, B., Seidavi, A., & Phillips, C. J. C. (2023). The Effects of Replacing Wheat and Soyabean Meal with Duckweed (Lemna Minor) and Including Enzymes in the Diet of Laying Hens on the Yield and Quality of Eggs, Biochemical Parameters, and their Antioxidant Status. *Animal Science Journal*, *94*(1), 13888. https://doi.org/10.1111/asj.13888

Bianchi, E., Biancalani, A., Berardi, C., Antal, A., Fibbi, D., Coppi, A., Lastrucci, L., Bussotti, N., Colzi, I., Renai, L., Scordo, C., Del Bubba, M., & Gonnelli, C. (2020). Improving the Efficiency of Wastewater Treatment Plants: Bio-Removal of Heavy-Metals and Pharmaceuticals by Azolla Filiculoides and Lemna Minuta. *Science of The Total Environment*, *746*, 141219. https://doi.org/10.1016/j.scitotenv.2020.141219

Butcher, D. J. (2005). Atomic Absorption Spectrometry | Interferences and Background Correction. *Encyclopedia of Analytical Science*, 157-163. https://doi.org/10.1016/b0-12-369397-7/00025-x

Chowdhury, A. I., & Alam, M. R. (2024). Health Effects of Heavy Metals In Meat and Poultry Consumption in Noakhali, Bangladesh. *Toxicology Reports*, *12*, 168-177. https://doi.org/10.1016/j.toxrep.2024.01.008

Darwish, W. S., Atia, A. S., Khedr, M. H. E., & Eldin, W. F. S. (2018). Metal Contamination in Quail Meat: Residues, Sources, Molecular Biomarkers, and Human Health Risk Assessment. *Environmental Science and Pollution Research*, *25*(20), 20106-20115. https://doi.org/10.1007/s11356-018-2182-0

Demann, J., Petersen, F., Dusel, G., Bog, M., Devlamynck, R., Ulbrich, A., Olfs, H.-W., & Westendarp, H. (2022). Nutritional Value of Duckweed as Protein Feed for Broiler Chickens-Digestibility of Crude Protein, Amino Acids and Phosphorus. *Animals*, *13*(1), 130. https://doi.org/10.3390/ani13010130

El-Katcha, M. I., Soltan, M. A., Shewita, R., Abdo, S. E., Sanad, A. S., Tufarelli, V., Alagawany, M., & El-Naggar, K. (2021). Dietary Fiber and Lysolecithin Supplementation in Growing Ducks: Effect on Performance, Immune Response, Intestinal Morphology and Lipid Metabolism-Regulating Genes. *Animals*, *11*(10), 2873. https://doi.org/10.3390/ani11102873

F.A.O. (2017). *Food and Agriculture Organization of the United Nations Statistics*.

Goyal, D., Yadav, A., Prasad, M., Singh, T. B., Shrivastav, P., Ali, A., Dantu, P. K., & Mishra, S. (2020). Effect of Heavy Metals on Plant Growth: An Overview. *Contaminants in Agriculture*, 79-101. https://doi.org/10.1007/978-3-030-41552-5_4

Gule, A. H., Derese, D. B., Erge, C. M., Girgo, U. G., & Ejeta, H. K. (2023). Effect of Dietary Supplementation of Duckweed on Growth Performance, Carcass and Non-Carcass Traits of Horro Rams Fed on a Commercial-Based Diet. *Heliyon*, *9*(7), 17820. https://doi.org/10.1016/j.heliyon.2023.e17820

Han, J. L., Pan, X. D., & Chen, Q. (2022). Distribution and Safety Assessment of Heavy Min Fresh Mfrom Zhejiang, China. *Scientific Reports*, *12*(1), 3241. https://doi.org/10.1038/s41598-022-07214-3

Ihedioha, J. N., Okoye, C. O. B., & Onyechi, U. A. (2014). Health Risk Assessment of Zinc, Chromium, and Nickel from Cow Meat Consumption in an Urban Nigerian Population. *International Journal of Occupational and Environmental Health*, *20*(4), 281-288. https://doi.org/10.1179/2049396714y.0000000075

Indarsih, B., & Tamsil, M. H. (2012). Feeding Diets Containing Different Forms of Duckweed on Productive Performance and Egg Quality of Ducks. *Media Peternakan*, *35*(2), 128-132. https://doi.org/10.5398/medpet.2012.35.2.128

Jadia, C. D., & Fulekar, M. H. (2009). Phytoremediation of Heavy MRecent Techniques. *African Journal of Biotechnology*, *8*, 921-928.

Khellaf, N., & Zerdaoui, M. (2010). Growth Response of the Duckweed Lemna Gibba L. to Copper and Nickel Phytoaccumulation. *Ecotoxicology*, *19*(8), 1363-1368. https://doi.org/10.1007/s10646-010-0522-z

Kuzniacka, J., Adamski, M., Czarnecki, R., & Banaszak, M. (2014). Results of Rearing Broiler Chickens Under Various Systems. *Journal of Agricultural Science*, *6*(4), 19-25. https://doi.org/10.5539/jas.v6n4p19

Lasfar, S., Monette, F., Millette, L., & Azzouz, A. (2007). Intrinsic Growth Rate: A New Approach to Evaluate the Effects of Temperature, Photoperiod and Phosphorus-Nitrogen Concentrations on Duckweed Growth Under Controlled Eutrophication. *Water Research*, *41*(11), 2333-2340. https://doi.org/10.1016/j.watres.2007.01.059

Leng, R. A., Stambolie, J. H., & Bell, R. (1995). Duckweed - a potential high-protein feed resource for domestic animals and fish. *Livestock Research for Rural Development*, *7*(1), 36.

Leung, H., Arrazola, A., Torrey, S., & Kiarie, E. (2018). Utilization of Soy Hulls, Oat Hulls, and Flax Meal Fiber in Adult Broiler Breeder Hens. *Poultry Science*, *97*(4), 1368-1372. https://doi.org/10.3382/ps/pex434

Liang, G., Gong, W., Li, B., Zuo, J., Pan, L., & Liu, X. (2019). Analysis of Heavy Metals in Foodstuffs and an Assessment of the Health Risks to the General Public via Consumption in Beijing, China. *International Journal of Environmental Research and Public Health*, *16*(6), 909. https://doi.org/10.3390/ijerph16060909

Maldonado, I., Moreno Terrazas, E. G., & Vilca, F. Z. (2022). Application of Duckweed (Lemna Sp.) and Water Fern (Azolla Sp.) in the Removal of Pharmaceutical Residues in Water: State of Art focus on Antibiotics. *Science of The Total Environment*, *838*, 156565. https://doi.org/10.1016/j.scitotenv.2022.156565

Men, B. X., Ogle, B., & Lindberg, J. E. (2002). Use of Duckweed as a Protein Supplement for Breeding Ducks. *Asian-Australasian Journal of Animal Sciences*, *15*(6), 866-871. https://doi.org/10.5713/ajas.2002.866

Miltko, R., Majewska, M. P., Wojtak, W., Białek, M., Kowalik, B., & Czauderna, M. (2024). Comparing the chemical composition of lesser duckweed (*Lemna minor* L.) grown in natural and laboratory settings. *Journal of Animal and Feed Sciences*, *33*(3), 357-367. https://doi.org/10.22358/jafs/189963/2024

Mwale, M., & Gwaze, F. R. (2013). Characteristics of Duckweed And its Potential as Feed Source for Chickens Reared for Meat Production: A Review. *Scientific Research and Essays*, *8*(18), 689-697.

Omotoso, S. O., Ajayi, D. E., Fagbenro, R. B., Oyogho, E. O., Oso, Y. A. A., & Babayemi, O. J. (2023). Duckweed as a Non-Conventional Forage for Ruminants in the Tropics. *Slovak Journal of Animal Science*, *56*(4), 42-51. https://doi.org/10.36547/sjas.838

Putrayasa, I. K. E. A., Mahardika, I. G., & Sudiastra, I. W. (2024). Kecernaan Nutrien Ransum Komersial Yang Disubstitusi Dengan Duckweed (Lemna Minor) Fermentasi Saccharomyces Cerevisiae Pada Broiler. *Jurnal Peternakan Tropika*, *12*, 318-334.

Rehman, A. U., Nazir, S., Irshad, R., Tahir, K., ur Rehman, K., Islam, R. U., & Wahab, Z. (2021). Toxicity of Heavy Metals In Plants And Animals and their Uptake by Magnetic Iron Oxide Nanoparticles. *Journal of Molecular Liquids*, *321*, 114455. https://doi.org/10.1016/j.molliq.2020.114455

Scutarașu, E. C., & Trincă, L. C. (2023). Heavy Metals in Foods and Beverages: Global Situation, Health Risks and Reduction Methods. *Foods*, *12*(18), 3340. https://doi.org/10.3390/foods12183340

Shammout, M. W., & Zakaria, H. (2015). Water Lentils (Duckweed) In Jordan Irrigation Ponds as a Natural Water Bioremediation Agent and Protein Source for Broilers. *Ecological Engineering*, *83*, 71-77. https://doi.org/10.1016/j.ecoleng.2015.05.041

Singh, D., Gupta, R., & Tiwari, A. (2011). Phytoremediation of Lead from Wastewater Using Aquatic Plants. *International Journal of Biomedical Research*, *2*(7). https://doi.org/10.7439/ijbr.v2i7.124

Standar Nasional Indonesia. (2009). Batas Maksimum Cemaran Logam Berat dalam Pangan. *SNI*, *7387*(2009), 15-17.

Sulaiman, A., & Irawan, dan B. (2020). Utilization of Duckweed (Lemna minor) in the Feed Diet to Improve Yolk Color of Eggs and Reduce Cholesterol Levels of Alabio Duck Eggs. *Prosiding Seminar Nasional Lingkungan Lahan Basah*, *5*(2), 56-62.

Suljević, D., Hodžić-Klapuh, L., Handžić, N., & Fočak, M. (2020). Morpho-Functional Alterations in Lymphocytes and Erythrocytes Of Japanese Quail Due to Prolonged in Vivo Exposure to Heavy Metal Complexes. *Journal of Trace Elements in Medicine and Biology*, *59*, 126472. https://doi.org/10.1016/j.jtemb.2020.126472

Supriatman, P., Dihansih, E., & Anggraeni, A. (2017). Production Performance of Male Local Ducks (Anas Plathyrinchos) Fed Torch Ginger Flower (Etlingera Elatior) Solution Included in Commercial Ration. *Jurnal Peternakan Nusantara*, *3*(2), 89-94. https://doi.org/10.30997/jpnu.v3i2.928

Susanti, R., Widiyastuti, K., Yuniastuti, A., & Fibriana, F. (2020). Feed and Water Management May Influence the Heavy Metal Contamination in Domestic Ducks from Central Java, Indonesia. *Water, Air, & Soil Pollution*, *231*(4), 177. https://doi.org/10.1007/s11270-020-04559-1

Susanti, R., Yuniastuti, A., Dafip, M., & Fibriana, F. (2022). Correlation of Heavy Metals Cd, Cr, Cu, Hg, Pb, and Zn with Intestinal Bacteria in Anas platyrhynchos L. Duck. *HAYATI Journal of Biosciences*, *29*(4), 459-467. https://doi.org/10.4308/hjb.29.4.459-467

Tanuwiria, U. H., & Mushawwir, A. (2020). Hematological and Antioxidants Responses of Dairy Cow Fed with a Combination of Feed and Duckweed (Lemna Minor) as a Mixture for Improving Milk Biosynthesis. *Biodiversitas Journal of Biological Diversity*, *21*(10). https://doi.org/10.13057/biodiv/d211038

Van Soest, P. J., Robertson, J. B., & Lewis, B. A. (1991). Methods for Dietary Fiber, Neutral Detergent Fiber, and Nonstarch Polysaccharides in Relation to Animal Nutrition. *Journal of Dairy Science*, *74*(10), 3583-3597. https://doi.org/10.3168/jds.s0022-0302(91)78551-2

Wang, H., Dong, Y., Yang, Y., Toor, G. S., & Zhang, X. (2013). Changes in Heavy Metal Contents in Animal Feeds and Manures in an Intensive Animal Production Region Of China. *Journal of Environmental Sciences*, *25*(12), 2435-2442. https://doi.org/10.1016/s1001-0742(13)60473-8

Widayanti, E., & Widwiastuti, H. (2018). Analisis Kandungan Logam Cadmium Pada Daging Daerah Dinoyo Kota Malang. *Prosiding SENATI*, *4*(1), 361-364.

Zezulka, Š., Kummerová, M., Babula, P., & Váňová, L. (2013). Lemna Minor Exposed to Fluoranthene: Growth, Biochemical, Physiological and Histochemical Changes. *Aquatic Toxicology*, *140-141*, 37-47. https://doi.org/10.1016/j.aquatox.2013.05.011

Ziegler, P., Sree, K. S., & Appenroth, K.-J. (2017). The uses Of Duckweed in Relation to Water Remediation. *Desalination and Water Treatment*, *63*, 327-342. https://doi.org/10.5004/dwt.2017.0479