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POTENTIAL BENEFITS OF WOOD VINEGAR DILUTED IN DRINKING WATER ON MEAT GUALITY AND GREENHOUSE GAS EMISSIONS REDUCTION IN MUSCOVY DUCK

Bounmy KEOHAVONG[1], Thanousinh KANDEE[1]
and Seevone NORGERKHAMSAYSIONG[1]

1 Souphanouvong University, LAOS; bounmy@su.edu.la (B. K.); thanousinh@su.edu.la (T. K.); seevonesiong@gmail.com (S. N.)

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Abstract

The experiment was conducted to investigate the effects of different levels of wood vinegar diluted in drinking water on meat quality and gas emissions in Muscovy duck. A total of 60 male of Muscovy ducks were randomly allotted to four groups at 4 weeks of age, each group comprised 15 birds. Wood vinegar (WV) was daily diluted in drinking water of the level WV 0%, WV 0.50%, WV 1% and WV 1.5%. Experimental feeding was conducted for 6 weeks. The diet and water were fed *ad libitum*. Six adult Muscovy ducks were randomly selected from each group with similar live weight for further analyses. Meat quality and gas emissions parameters were conducted at the end of the experimental. The gas emitted was performed at day 3, 6 and 9 of the storage times. The results of carcass yield in WV0.5 and WV1 higher than WV0.5 and control groups. Abdominal fat in treatment groups decreased. Chilling cooking losses showed not significant different. The relative yellowness of pectoral muscle chilled 45 min indicated the lowest value, and those the rest values of pectoralis of both chilled 24 h and 7 days were not differed. The relative redness of leg muscles chilled 7 days in WV0.5, WV1, and WV1.5 showed lower than control group, the lowest value was observed in WV1.5. Gas emissions in WV1 and WV1.5 of hydrogen sulfide emitted on day 3 were significantly decreased. Nonetheless, methane in WV1 and WV1.5 were emitted 0% and WV0.5 was also significantly decreased. In conclusion, wood vinegar has the potential benefit to partially replace and/or the alternatives to antibiotic use. Also, wood vinegar could be served as additives, since it can prevent or reduce H_2S and CH_4 in Muscovy duck production.

Keywords: Wood Vinegar, Meat Quality, Greenhouse Gas Emissions

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Introduction

In animal husbandry as well as poultry production, there have been investigated and identified the alternatives to antibiotic use for growth promotion and feed efficiency (Doyle, 2001). After antibiotics banned by the European Union for poultry, seeking new natural resource as well as plant riches in organic compounds thus as *Tinospora Crispa* (Keohavong & Maliya, 2021) and *Piper ribesioides* (Vaenvongthong et al., 2024) or synthetic agents which able to successfully substitute these antibiotics has been increasing interest in research and development (Lemos et al., 2016). Due to antibiotic has been confirmed the serious problems of its residues in human food as well as many kinds of animal products, which has led to the public perception and regulatory pressure of the necessary requirement to ban antibiotics from feed additive in animal production (Han et al., 2007). In poultry, the use of growth promoter is considered as a potential issue in animal husbandry, moreover, this widespread practice was not free from the criticism, and it was considered as the indiscriminate use of antibiotics for this purpose (Gessica et al., 2019).

Muscovy ducks (*Cairina moschata*) are popular in various regions across Southeast Asia, including Laos. Due to its adaptability and suitability for local farming practices, regarding its meat satisfactory and its relevance such as culinary importance, nutritional value, cultural practices, economic role, sustainability and market trends. Muscovy duck is mainly produced for meat consumption; therefore, its meat quality is concerned as a key requirement of the production purposes. Raising Muscovy duck can be a viable source of income for smallholder farmers. The demand for duck meat in the local market as well as for festive occasions can provide financial benefits for families. Muscovy duck meat driven by both local consumption and potential export. Recently, its meat quality and production performance are well known and verified (Vaenvongthong et al., 2024; Bounphong et al., 2021).

Wood vinegar, the charcoal production processing was produced by-product known as “wood vinegar” which obtained by distilling the smoke arising from burning wood, wood vinegar contains a complex mixture of water and organic compounds ranged 80-90% and 10-20%, respectively (Sakaguchi et al., 2007). Moreover, this by-product contains several benefit organic pounds for health as well as various phenolic compounds and antioxidants that may help protect animals from oxidative stress and inflammation, the main compound such as guaiacol, cresol, acetic acid, formic acid and propionic acid that could be refined by fractional distillation to produce a food-grade product (Sakaguchi et al., 2007). There are several studies have been investigated and the potential effects of wood vinegar on the performance of livestock production and results have shown improvements in growth performance, feed efficiency and overall health indicators, especially in monogastric animals such as in broiler quail (Gessica et al., 2019), cockerel chickens (Samanya & Yamauchi, 2002), laying hens (Amany et al., 2020; Sakaida et al., 1987; Li & Ryu, 2001), and weanling pigs (Choi et al., 2009). Also, wood vinegar might inhibit harmful coliforms in the intestinal tract by blocking possible intestinal receptors of these pathogens or by secreting toxic metabolites against gram negative bacteria of the monogastric animal that shown the greater population of *Lactobacilli* in the ileum (Cranwell et al., 1976; Danielson et al., 1989). By promoting a healthy gut environment and supporting physiological functions, wood vinegar supplementation has been linked to reduce stress levels in animals, possibly through its effects on gut health, immunity, and overall well-being. In the chicken study shown that wood vinegar might be the most effective substance for activating the intestinal absorptive function, and that the functional activation of whole intestine, including the ileum may induce a slight growth performance elevation (Samanya & Yamauchi, 2002). While the existing literature suggests a range of potential benefits of wood vinegar in animal studies, it may contribute to better animal welfare and stress management in poultry production systems, the further research is needed to confirm these findings, to determine optimal dosage levels and assess long-term effects on different species and production systems. In addition, based on the climate change, the Environmental Protection Agency (EPA) estimated that greenhouse gas emission originated from agriculture over 6.4%, among this amount the primary greenhouse gases emitted by animal farms covered 53.5% (Dunkley & Dunkley, 2013). The greenhouse gas emission mainly emitted by agricultural activities are carbon dioxide (CO_2) and methane (CH_4) (Johnson et al., 2007). In recently, there has been a few studies using wood vinegar in Muscovy duck, the finding shown some potential benefit on growth performance and feed efficiency (Norgerkhamsaysiong et al., 2023). Other study shown that wood vinegar is being used to remove the odor of ammonia in animal farms (Park et al., 2003).

However, continued scientific investigations will help expand our understanding of the applications of wood vinegar in animals and its potential contributions to sustainable and efficient livestock productions are needed. Nonetheless, the daily requirement of feed and water, poultry required drinking water twice as compared to the feed consumptions. In our best knowledge, the previous research using wood vinegar through drinking water in poultry is limited. Therefore, we conducted this study to determine the different levels of wood vinegar diluted in drinking water on meat quality and greenhouse gas emissions in Muscovy duck.

Literature Review

Wood Vinegar in Poultry Research

Wood vinegar has been used for over a century as a fertilizer and antimicrobial agent, and its impacts on ecosystems have become increasingly important (Morales et al., 2022), specifically as an inhibitor for greenhouse gas mitigation in animal productions. As global defined, wood vinegar as a by-product obtained by the smoke arising from the charcoal productions process or burning wood, the product was obtained in liquid form and its mains composition as pyroligneous acid which is a liquid by-product obtained from the carbonization of wood and other lignocellulosic raw materials by trapping the pyrolysis gases through a condensing apparatus. It contains a complex mixture of organic compounds, including furans, acetic acid, methanol, phenols, ketones and various other organic acids (Miyasaka et al., 1999; Encarnacao, 2001; Araujo et al., 2017; Pimenta et al., 2018). In poultry research, wood vinegar has garnered interest for several potential applications, including health and growth promotion, natural additive, improving egg quality, environmental management, stress reduction, and antioxidant properties. While the potential benefits of wood vinegar in poultry are promising, some studies suggest that wood vinegar contained antimicrobial properties, which could help reduce the incidence of disease and gas emission in poultry. This could lead to improved growth rates and feed efficiency. Due to its organic composition, wood vinegar in being explored as a natural additive in poultry feed and drinking water. This can offer a more sustainable alternative to synthetic growth promoters and antibiotics. Some research indicates that adding wood vinegar to the diets of laying hens improved eggshell quality, hen-day egg production and yolk color (Amany et al., 2020; Sakaida et al., 1987; Li & Ryu, 2001). Wood vinegar can be used in waste management practices within poultry farming, helping to reduce odors and potential pathogens in manure. There are indications that wood vinegar could help in reducing stress levels in poultry, which can positively affect their overall health and productivity. In addition, dietary wood vinegar enhanced intestinal villi, feed conversion ratio, hen-day egg production and hatchability (Sakaida et al., 1987; Samanya & Yamauchi, 2002). A promising research line on wood vinegar appliance as a supplement as feed additive in monogastric animal diets, it is able to improve digestibility, nutrient absorption, and better performance in laying hens fed with diets containing variable levels of wood vinegar has been reported as well (Kook & Kim, 2002; Sakaida et al., 1987; Li & Ryu, 2001).

The Quality of Duck Meat

Duck meat quality can be evaluated based on several factors, including water holding capacity, sensory evaluation, color, pH, flavor, juiciness, texture, fat content and nutritional values. The nutritional profiles may vary based on the diets and living conditions. Duck meat has a rich unique flavor that is often described as more robust than chicken and turkey, the flavors are varied, depending on the diet they were fed and breeds. Muscovy ducks are known for their mild flavor compared to others breeds. Muscovy duck is characterized by a fast growth rate, high slaughter weight, good feed conversion. The world duck meat production in 2018 accounted 4,464,925 tons or around 3,5% of the overall poultry meat available. The majority of duck meat in the world was produced in Asia around 83%, Europe 11.7% and the other continents 5.3% (Food and Agriculture Organization Corporate Statistical Database, 2019) Muscovy duck had more favorable chemical composition as well as protein, fat, mineral contents and poorer tenderness and microstructural characteristics (Kokoszynski et al., 2021). Other advantages of Muscovy ducks include higher breast and leg muscle percentages in the carcass, a lower percentage of skin with subcutaneous fat and of abdominal fat, and meat of better quality compared to Pekin ducks (Hassan et al., 2018). Duck meat is a good source of high-quality protein, essential amino acids, essential vitamins and minerals. breast muscle of Muscovy duck had a higher protein and mineral contents and lower lipid content (Larzul et al., 2006), and also the sensory evaluation has shown that the breast muscle of Muscovy ducks are less juicy and tender, and more fibrous compared to the breast muscle of Pekin duck (Baeza et al., 2005). Well known, the meat color is the first choice of the consumer decisions. Fresh duck meat typically has a darker color, ranging from deep red to dark pink. Skin color can also indicate quality, the skin should be intact with a glossy appearance and free from blemishes or discoloration. The meat color is caused differences in the degree of vascularization and in the contents of haemoglobin, myoglobin and cytochrome C. There are three different indicators of meat color observations as lightness (L*), redness (a*) and yellowness (b*). At the market age of duck, breast muscle of Muscovy duck shown the lightness value higher than in Pekin (Huda et al., 2011). Earlier study reported (Bounphong et al., 2021) that the color values of Muscovy duck (breast meat) such as the lightness, redness and yellowness ranged 16.91-18.69 (L*), 20.75-21.92 (a*) and 9.61-9.93 (b*), respectively. Nonetheless, what holding capacity is defined as an important indicator of meat quality. Duck meat containing water varied among slaughter age and meat types. The muscle of Muscovy duck had a higher water content (from 76.12% to 76.41%) than in Pekin (from 74.37% to 76.04%) (Marzoni et al., 2014). The quality of duck meat can be evaluated based on its tender and juicy texture, the age of the duck at the time of processing, as well as the cooking method used, which can significantly affect the tenderness, and well known in younger duck tend to have more tender meat. Moreover, duck meat is generally higher in fat content compared to chicken and other poultry breeds. Breast muscle containing fat from 2.22% to 2.48% (Baltic et al., 2015).

The Greenhouse Gas Emissions from Livestock Farming

Livestock production is a major contributor to greenhouse gas emissions, and it will play a significant role in the mitigation effort. Beyond evaluating baseline emissions, it is imperative the chart pathway to lower the greenhouse gas emissions produced by the world's livestock systems in the face of a growing global population and a projected 20 percent increase in demand for terrestrial animal products by 2050. Earlier reported that various mitigation options exist to reduce greenhouse gases while meeting increased demand for terrestrial animal-sourced foods. The outline pathways to reduce gas emissions, the main scenarios application can be well-established best practices in animal management. Methane and carbon dioxide are both harmful gases emitted by agri-food system, the emissions are vary based on the facilities, management and animal species. Analysis of mitigation options in livestock systems, the finding shown that cattle of both meat and milk farming contributed around 3.8 $GtCO_2$

equivalent per year or equal 62% of total livestock farming emissions. The gas emissions from pig, chicken, buffaloes and other small ruminant productions are accounted 14%, 9%, 8% and 7%, respectively (Minichiello, 2023). It is important to note that greenhouse gas emissions mainly the gases such as CO_2, N_2O and CH_4, which account for 60% of total atmospheric emissions (Intergovernmental Panel on Climate Change, 2007). In livestock farming, the majority of direct carbon dioxide emissions from animal production are usually from fossil use. As well known, the use of propane or natural gas in furnaces or incinerator and the use of diesel gas to operate farm equipment and generators results mostly in CO_2 emissions or known as “mechanical emissions”. The main cause of agricultural nitrous oxide emissions is from the application of nitrogen fertilizers and animal manures. Based on the life cycle assessment of beef cattle, 86.15% of the greenhouse gases are emitted during the production stage, during the production of pork is accounted 68.51% of emissions, and 47.82% of greenhouse gas emissions occur during the production stage of broiler chickens. During swine production, manure management is the major source of the emissions, and propane use during broiler chicken production. The source of greenhouse gas emissions from beef cattle production stage comes from enteric fermentation (Dunkley & Dunkley, 2013). A new study has found that global greenhouse gas emissions from the production of food has accounted 17,318 $TgCO_2$ per year of which corresponds to the production of animal-based food of 57%, including livestock feed (Xu et al., 2021).

Recent literature highlights different strategies to mitigate greenhouse gas emissions in the livestock sector. Livestock production should consider animal welfare amongst other sustainability metrics, and animal welfare is also a criterion of sustainability, and any strategies designed to reduce the carbon footprint. Increasing productivity efficiency, diet digestibility, intensive housing, improving health and welfare can be promised to reduce the livestock carbon footprint (Llonch et al., 2017).

Research Methodology

Experimental Design

A total of sixty male of Muscovy ducks were randomly allotted to four groups at 4 weeks of age (bodyweight: 900±10 g/bird), each group comprised 15 birds. Wood vinegar (WV) was daily diluted in drinking water of the level WV 0% (WV0: Control), WV 0.50% (WV0.50), WV 1% (WV1) and WV 1.5% (WV1.5). Experimental feeding (commercial diet) was conducted for 6 weeks (or the trial ended at 10 weeks of age, as a market demand). The diet and water were fed *ad libitum*. The measurements of the abdominal organ characteristics, meat samplings and manure samplings were conducted at the end of the feeding trial. This experiment was approved by the Research Committee for Animal Experimentation in Souphanouvong University (no.171/SU).

Characteristics of Internal Organs

The characteristics of internal organs were performed at the end of the feeding trial. Six adult Muscovy ducks were randomly selected from each group with similar live-weight (2,241.25±141g/bird) and its individual live-weights were recorded. Each bird used as an experimental unit for statistical analysis. They were sacrificed by neck cut, scalded with hot water at the temperature of 80ºC for 3 minutes. The birds were subsequently defeathered and carefully eviscerated manually. The warm carcass weight was obtained and the dressing percentage calculated (Price, 1967). The liver, spleen, lung, heart, gizzard and abdominal fat were collected and carefully removed its attached membranes (if any), individual organ weight was recorded. The percentages of internal organs were calculated (Omojola, 2007) by using the following adapted equation

$$\text{Abdominal Organ (\%)} = \frac{100[\text{ weight of abdominal organs}]}{\text{Weight of carcass}}$$

Meat Quality Attributes

Chilling and Cooking Losses: Chilling loss was analyzed using the similar method described by Omojola (2007) with slightly adjusted. Samples for chilling loss were taken from the pectoralis and leg muscle (right) and cut into approximately 30 g per sample. Six samples were selected in sequence from the pectoralis and/or leg muscle and weighed before chilling at 3ºC for 45 minutes. Another 6 samples of pectoralis and/or leg muscle were also weighed and chilled at 3ºC for 24 hours. And other 6 samples of pectoralis and/or leg muscle were also weighed and chilled at 3ºC for 168 hours (7 days). Chilling loss was determined as the difference between the weight before chilling and chilled weight, by using the following equation.

$$\text{Chilling Losses (\%)} = \frac{100[\text{ weight of sample before chilling} - \text{weight of chilled sample}]}{\text{Weight of sample before chilling}}$$

Cooking loss was determined using the similar method described by An et al. (2015) with slightly adjusted. The same samples as used for chilling loss. Chilled samples obtained from three different periods were used to boil at 150ºC for 10 minutes and then cooled to room temperature to determine cooking loss according to the equation described by Omojola (2007).

Colors and pH: The samples of pectoralis and leg muscle were collected according to the method described by (Kokoszynski et al., 2021). Briefly, at the end of the experimental feeding, a total of six Muscovy duck were randomly selected from each group for meat colors and pH analysis. The slaughtering process was done as described above. The pretreatment of meat samples of both raw pectoralis and leg muscle were also stored at 3ºC for three different periods (45 minutes, 24 hours and 7 days). The meat color was determined on the inner side of raw pectoralis major muscle from the side of the keel. Meat color of raw leg muscle was done from the side of the thigh and drumstick bones. To determine the three parameters of meat color, the measurement was done using a Konica Minolta colorimeter (model CR310, Konica Minolta, Osaka, Japan). Color lightness (L*), relative redness (a*) and relative yellowness (b*) were determined using the CIE Lab system (Commission Internationale de l'Eclairage, 1986).

To measure pH (pH meter: model pH3210 WTE, Germany) of meat of both raw pectoral and leg muscle, using the same samples of meat color measurement. The measurement was conducted in duplicates for each sample.

Greenhouse Gas Emissions

Gas emissions was conducted at the end of the experimental feeding, and it had performed prior meat quality measurements. The birds from each group were placed into 3 cages (5 birds per cage), and the feces collector was placed under the cage. Feces samples (100g/cage) were stored in the plastic bottles (350ml) in anaerobic conditions. The gas emitted was performed at day 3, 6 and 9 of the storage times. The gas analyzer's sensor (model SKY8000-WH-M4, Shenzhen Yuante Technology Co., LTD) was connected into the bottle individually, and emitted gas of H_2S (0 - 5 0 0 0 ppm), CO_2 (0-100%VOL), O_2 (0-100%VOL), and CH_4 (0-100%VOL) was recorded.

Statistical Analysis

The individual sample used as an experimental unit for statistical analysis. The data was analyzed by Duncan's test using the General Linear Model procedure of SAS program, version 9.1.2 (2004). Differences are considered to be significant at $p < 0.05$. Significant differences will be compared between feeding group and/or treatment.

Research Results

Characteristics of Internal Organs

The present study showed that wood vinegar could be improved ($p < 0.05$) that the values of internal organs, and its detail information are shown in the Table 1. The carcass yield in WV1 and WV1.5 showed higher than WV0.5 and control groups ($p = 0.008$). The great carcass yield of Muscovy duck was showed in WV1.5 group which indicated highest value and higher than the control group at 5.89%. The internal organs of Muscovy duck also significantly differences ($p \leq 0.039$) among the groups. The abdominal fat is the most sensitive for most consumer concerning, the result of this study showed that most of Muscovy duck received wood vinegar could be decreased the abdominal fat ($p = 0.007$) when compared to the control group.

Table 1 Effects of wood vinegar on the percentages of dressing and the internal organs in Muscovy ducks.

Items[1] (%)	**Wood vinegar[2]**				**SEM**	**P-Value**
	WV0	**WV0.5**	**WV1**	**WV1.5**		
Dressing[3]	70.78	67.51	71.11	76.67	3.29	0.008
Liver	2.6	2.81	2.74	2.64	0.08	0.001
Gizzard	2.68	2.67	2.63	2.4	0.11	0.007
Abdominal fat	1.18	1.02	1.01	0.99	0.08	0.007
Heart	1.05	1.05	1.01	0.99	0.03	0.008
Spleen	0.85	0.89	0.9	0.86	0.02	0.039
Lung	1.33	1.37	1.32	1.28	0.03	0.012

P-Value = Probability Value; SEM = Standard Error of the Mean.

[1] The values of internal organs presented in the table expressed as in percentage of the carcass weight.

[2] The percentage of wood vinegar diluted in drinking water as WV0 = Wood vinegar 0%, WV0.5 = Wood vinegar 0.5%, WV1 = Wood vinegar 1%, and WV1.5 = Wood vinegar 1.5%.

[3] Dressing = The individual defeathered and eviscerated warm carcass was expressed as in percentage of live weight.

Quality of Muscovy Duck Meat

The parameters of meat quality are varied, this study has been conducted on the values of chilling loss, cooking loss, meat colors and pH of both pectoralis and leg muscles. The results of chilling (Table 2) and cooking (Table 3) losses showed not significant different ($p > 0.05$).

It was observed that the relative yellowness (b*) of pectoral muscle chilled 45 min indicated the lowest ($p = 0.054$) value, and those the rest values of pectoralis of both chilled 24 h and 7 days were not affected ($p > 0.05$) by wood vinegar (Table 4). The relative redness (a*) value of the leg muscles chilled 7 days in WV0.5, WV1, and WV1.5 showed lower ($p = 0.025$) than control group, the lowest value was observed in WV1.5. Therefore, this study was indicated that the color lightness (L*), relative redness (a*) and the relative yellowness (b*) of leg muscle in early stage of the storage time (45 min and 24 h) showed not significant ($p > 0.05$).

Moreover, the present study found that the pH values of the pectoral and leg muscles chilled 45 min, 24 h and 7 days of WV0.5, WV1, and WV1.5 showed better and/or constantly values ($p < 0.05$) than control. The best pH value of pectoral muscle chilled 45 min, 24 h and 7 days were found in WV0.5 ($p = 0.030$), WV1.5 ($p = 0.005$) and WV1.5 ($p = 0.003$), respectively. For the leg muscle, the highest pH value of meat chilled 45 min, 24 h and 7 days were found in WV1 ($p = 0.002$), WV0.5 ($p = 0.003$) and WV0.5 ($p = 0.020$), respectively. The result was also indicated that the most constantly pH values of both pectoral and leg muscles after chilled 7 days were observed in the whole group of wood vinegar, while the control group was rapidly decreased ($p < 0.05$).

Table 2 Effects of wood vinegar on chilling losses in the Muscovy duck muscles (%).

Chilling times	Wood vinegar*				SEM	P-Value
	WV0	**WV0.5**	**WV1**	**WV1.5**		
Pectoral muscles						
45 minutes	8.14	7.43	7.27	7.57	0.83	0.885
24 hours	8.55	7.75	7.87	7.57	0.62	0.710
7 days	8.57	7.82	8.18	7.85	0.99	0.940
Leg muscles						
45 minutes	7.33	7.06	7.20	7.06	0.89	0.995
24 hours	7.91	7.62	7.46	7.83	1.49	0.996
7 days	8.18	7.74	8.24	7.93	0.14	0.163

P-Value = Probability Value; SEM = Standard Error of the Mean.
* The percentage of wood vinegar diluted in drinking water as WV0 = Wood vinegar 0%, WV0.5 = Wood vinegar 0.5%, WV1 = Wood vinegar 1%, and WV1.5 = Wood vinegar 1.5%.

Table 3 Effects of wood vinegar on cooking losses in the Muscovy duck muscles (%).

Cooking times	Wood vinegar*				SEM	P-Value
	WV0	**WV0.5**	**WV1**	**WV1.5**		
Pectoral muscles						
45 minutes	36.59	32.60	34.78	33.17	2.73	0.743
24 hours	37.27	34.62	41.07	33.71	2.99	0.411
7 days	38.16	38.46	41.14	34.96	2.44	0.454
Leg muscles						
45 minutes	35.83	32.89	33.13	34.16	1.66	0.626
24 hours	36.57	34.93	39.52	35.86	2.58	0.652
7 days	38.56	36.94	40.41	37.08	6.26	0.975

P-Value = Probability Value; SEM = Standard Error of the Mean.
* The percentage of wood vinegar diluted in drinking water as WV0 = Wood vinegar 0%, WV0.5 = Wood vinegar 0.5%, WV1 = Wood vinegar 1%, and WV1.5 = Wood vinegar 1.5%.

Table 4 Effects of wood vinegar on the colors of the Muscovy duck muscles.

Storage times	Colors	Wood vinegar*				SEM	P-Value
		WV0	**WV0.5**	**WV1**	**WV1.5**		
Pectoral muscles							
45 min	L*	34.45	32.07	35.76	33.97	4.96	0.959
	a*	11.5	14.16	14.19	13.81	1.76	0.684
	b*	10.14	9.57	10.28	6.73	0.66	0.054
24 h	L*	31.92	30.92	32.37	32.23	3.67	0.991
	a*	10.98	13.48	13.9	11.74	1.15	0.35
	b*	11	9.83	11.24	7.73	0.78	0.101
7 d	L*	30.95	28.13	29.6	31.6	3.09	0.859
	a*	10.43	12.37	11.33	10.37	0.5	0.126
	b*	12.55	10.6	12.07	9.85	1.03	0.346
Leg muscles							
45 min	L*	35.32	41.03	40.89	41.8	3.77	0.334
	a*	16.82	14.28	14	10.71	2.02	0.322
	b*	13.58	10.92	9.34	16.02	2.33	0.322
24 h	L*	33.15	38.94	37.88	38.05	2.86	0.54
	a*	14.95	12.92	12.33	10.41	1.29	0.24

	b*	14.13	13.55	10.27	16.98	2.04	0.28
7 d	L*	32.33	36.84	37.12	33.69	2.68	0.566
	a*	14.21	11.49	11.71	10.49	0.5	0.025
	b*	14.46	13.94	10.95	17.03	1.64	0.218

L* = Color lightness; a* = relative redness; b* = relative yellowness.
P-Value = Probability Value; SEM = Standard Error of the Mean.
* The percentage of wood vinegar diluted in drinking water as WV0 = Wood vinegar 0%, WV0.5 = Wood vinegar 0.5%, WV1 = Wood vinegar 1%, and WV1.5 = Wood vinegar 1.5%.

Table 5 Effects of wood vinegar on the pH values of the chilled muscle.

Storage times	Wood vinegar*				SEM	P-Value
	WV0	WV0.5	WV1	WV1.5		
Pectoral muscles						
45 minutes	5.48	5.58	5.54	5.56	0.02	0.030
24 hours	5.41	5.51	5.51	5.52	0.01	0.005
7 days	5.34	5.46	5.45	5.50	0.01	0.003
Leg muscles						
45 minutes	5.59	5.97	6.00	6.00	0.03	0.002
24 hours	5.56	5.93	5.92	5.85	0.03	0.003
7 days	5.51	5.84	5.76	5.77	0.04	0.020

P-Value = Probability Value; SEM = Standard Error of the Mean.
* The percentage of wood vinegar diluted in drinking water as WV0 = Wood vinegar 0%, WV0.5 = Wood vinegar 0.5%, WV1 = Wood vinegar 1%, and WV1.5 = Wood vinegar 1.5%.

Greenhouse Gas Emissions

The result of gas emissions shown in the Table 6. It was observed that the hydrogen sulfide (H_2S) emitted at day 3 of the WV1 and WV1.5 groups were significantly decreased ($p = 0.019$). Nonetheless, the methane (CH_4) emitted to zero (undetected) was observed in the both WV1 and WV1.5 groups, and the WV0.5 group was also significantly decreased ($p = 0.002$). In the early stage (day 3) of the fermentation process was not indicated any changes in both carbon dioxide (CO_2) and oxygen (O_2) emissions ($p > 0.05$). Moreover, at the longer fermentation times (day 6 and day 9) the emissions of H_2S, CO2, CH4, and O_2 were not significant differences ($p > 0.05$).

Table 6 Effects of wood vinegar on the greenhouse gas emissions from the Muscovy duck excretions.

Gases	Wood vinegar*				SEM	P-Value
	WV0	WV0.5	WV1	WV1.5		
Day 3						
H_2S, ppm	153.33	360.67	40.00	88.76	57.58	0.019
CO_2, %VOL	0.56	0.57	0.43	0.53	0.08	0.625
CH_4, %VOL	0.44	0.11	-	-	0.06	0.002
O_2, %VOL	0.94	1.90	2.10	0.39	1.26	0.753
Day 6						
H_2S, ppm	28.67	426.00	44.67	186.00	90.41	0.048
CO_2, %VOL	1.10	1.23	0.74	0.77	0.23	0.415
CH_4, %VOL	-	-	-	-	-	-
O_2, %VOL	1.26	0.45	0.43	0.62	0.52	0.660
Day 9						

H_2S, ppm	215.00	595.67	118.00	301.67	176.22	0.320
CO_2, %VOL	0.77	1.32	0.79	0.93	0.21	0.280
CH_4, %VOL	-	-	-	-	-	-
O_2, %VOL	0.12	1.05	1.86	0.78	1.04	0.704

P-Value = Probability Value; SEM = Standard Error of the Mean; CO_2 = Carbon dioxide; CH_4 = Methane; H_2S = Hydrogen sulfide; O_2 = Oxygen.

* The percentage of wood vinegar diluted in drinking water as WV0 = Wood vinegar 0%, WV0.5 = Wood vinegar 0.5%, WV1 = Wood vinegar 1%, and WV1.5 = Wood vinegar 1.5%.

Discussion

Characteristics of Internal Organs

According to the result of this study, the characteristics of internal organs and dressing percentages were influenced by wood vinegar. The dressing percentage as a key trait of economic importance. Current data showed that the dressing percentage of male Muscovy duck similarly with the standard value described by Omojola (2007). Moreover, the birds received wood vinegar at 1.5% of our study shown higher dressing percentage of 5.49% as compared with the previous reported by Omojola (2007), and the current result agreed with earlier reported by Gessica et al. (2019), they found that the wood vinegar improved carcass field in broiler quail. It was cleared that wood vinegar 1.5% could be increased the high dressing percent of Muscovy duck in the present study might be caused by the organic compounds in wood vinegar, which played as an important roles in growth performance and feed efficiency (Miyasaka et al., 1999; Encarnacao, 2001; Araujo et al., 2017; Pimenta et al., 2018). The internal organs such as liver, gizzard and intestine have very early growth (Leclercq & Carville, 1985). The results obtained in this study showed that the changes of internal organs could be directly affected by drinking water diluted wood vinegar, due to the potential effects and the important roles of wood vinegar in poultry performance has been varies reported (Amany et al., 2020; Sakaida et al., 1987; Li & Ryu, 2001). Muscovy duck at the market age as well as in welfare farming, its abdominal fat percentage usually around 18% (Bounphong et al., 2021) as similar value found in the control group of this findings. Surprisingly, the present study showed that the abdominal fat in birds received wood vinegar 1.5% decreased up to 16.10% as compared to the control. The reductions of abdominal fat have been agreed with the research findings of Sakaida et al. (1987) and Samanya & Yamauchi (2002), the formations of abdominal fat was well known influenced by wood vinegar as well as the activities of its an antioxidant compounds (Sakaguchi et al., 2007).

Quality of Muscovy Duck Meat

Based on the results of this finding, the chilling and cooking losses might be clearly confirmed that wood vinegar did not affect the quality of meat. In practically, based on our observations that the dilution level of wood vinegar at maximum of 1.5% is recommended for Muscovy duck as also to optimize the amount of water consumptions. The percentages of chilling and cooking losses in this finding were similar to the previous research (Bounphong et al., 2021; Omojola, 2007). The meat color in this study indicated that the color lightness (L*), relative redness (a*) and the relative yellowness (b*) of both pectoral and leg muscle which observed at three different stage periods (45 min, 24 h and 7 day) shown an overall unaffected by wood vinegar. Earlier studies (Huda et al., 2011; Bang et al., 2010) established the lightness (L* = 34.66) and redness (a* = 17.88) values of pectoral muscle were measured in Muscovy duck, which similar values in our study. Wood vinegar with 1.5% as a supplementing additive at late phase of poultry production could be promising tools for realizing the best improvement and safe for some quality parameters (Amany et al., 2020). The present study found that the best pH value was observed in the birds obtained wood vinegar. Nonetheless, wood vinegar contains a complex mixture of organic compounds. The pH value in our study indicated similar to the previous reported by Soltan (2008), who described that the organic acids could be decreased intestinal pH in chickens, which could be influenced into the muscle as this study has been observed. In the study by Kokoszynski et al. (2021), Moscovy duck have a significantly higher contents of fat and both pectoral and leg muscles compared the other meat-type ducks, which may suggest higher nutritive and dietetive values of meat of Muscovy duck, and thus they better met the expectations of most consumers, but in our study did not measured the sensory evaluations.

Greenhouse Gas Emissions

The present study showed that greenhouse gas emissions observed in earlier stage (day 3 of fermentation period) on the hydrogen sulfide (H_2S) and methane (CH_4) were decreased emissions. Wood vinegar decreased hydrogen sulfide (H_2S) emissions from Muscovy duck production up to 26.14% in the group of birds received wood vinegar 1%, the current data was greater than previous reported by Minichiello (2023) who indicated the hydrogen sulfide (H_2S) emissions from poultry production are accounted 9%. In contrast, this study showed methane (CH_4) emissions 0% in the groups of wood vinegar 0.5 and 1%, and even storage longer periods the values of methane (CH_4) emissions are also 0%, methane (CH_4) played an important role in emissions which accounted for 60% of total atmospheric emissions (Intergovernmental Panel on Climate Change, 2007). Since the emissions comes from enteric fermentation (Dunkley & Dunkley, 2013), when storage longer periods, hydrogen sulfide (H_2S) indicated to increased compared to the earlier stage. The conflict of the change might be occurred in technical error and/or practical performance during data collection in the laboratory. However, the emissions of both carbon dioxide (CO_2) and oxygen (O_2) in this study were not influenced by wood vinegar. Whatever, in our result showed lower emissions compare to finding of Xu et al. (2021) who reported that gas emissions from production of animal-based food of 57%.

Conclusion

In conclusion, wood vinegar has the potential benefit to partially replace and/or the alternatives to antibiotic use. Also, wood vinegar can be served as additives, since it can prevent or reduce H_2S and CH_4 in Muscovy duck production. Moreover, it can be benefitted to increase the carcass yield and quality of duck meat, and safety level of 1.5% diluted in drinking water for Muscovy duck is recommended. Wood vinegar diluted in drinking water is more appropriated compared to the dietary additive, since it is less preferred smell for animal. Nevertheless, using wood vinegar in poultry application with varied dilution levels and different poultry genotypes are carefully concerned.

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