Int. J. Poult. Sci., 2026, 25: 69-77 | DOI: 10.3923/ijps.2026.69.77

International Journal of Poultry Science

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RESEARCH ARTICLE

Effects of Urea-Treated Fermented Orange Peel Meal Fermentation Duration on Meat Organoleptic Properties and Apparent Nutrient Digestibility in Broiler Chickens

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Key words:
Broiler, chicken meat, digestibility, fermentation, organoleptic, poultry feed, urea

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Cite this Article:
Akanbi, O.M., T.S. Olugbemi, M. Afolayan, S.S. Ndams and H.I. Atta, 2026. Effects of urea-treated fermented orange peel meal fermentation duration on meat organoleptic properties and apparent nutrient digestibility in broiler chickens. Int. J. Poult. Sci., 25: 69-77.

Abstract

Objective: This study evaluated the effects of dietary inclusion of urea-treated fermented orange peel meal (FUTOPM) fermented for 3, 6 and 9 days with *Aspergillus niger* on the sensory attributes of broiler chicken meat and apparent nutrient digestibility.

Materials and Methods: Orange peels were collected, processed, treated with 1% urea, inoculated with a standardized A. niger culture and fermented anaerobically for 3, 6, or 9 days. A total of 240 broiler chickens were assigned to four dietary treatments (control and three FUTOPM diets at 20% inclusion) in a completely randomized design with three replicates per treatment. Sensory evaluation of cooked breast meat was conducted by a trained panel using a 9-point hedonic scale to assess appearance, flavor, texture, juiciness, tenderness and overall acceptability. Apparent nutrient digestibility was determined using the total fecal collection method over a seven-day period. Data were analyzed using the General Linear Model procedure of SAS and treatment means were separated using Duncan's Multiple Range Test at $p<0.05$.

Results: No significant differences ($p>0.05$) were observed among treatments for any sensory attribute, indicating that FUTOPM inclusion did not adversely affect meat palatability. Apparent nutrient digestibility improved with increasing fermentation duration. Crude protein digestibility increased to 92.67, 91.08 and 92.45% in the 3-, 6- and 9-day fermented diets, respectively, compared with 85.91% in the control. Crude fiber digestibility values were 81.35, 86.55 and 90.27% for the respective fermentation periods, versus 84.35% in the control. Ether extract digestibility was highest (92.15%) in the 3-day fermented diet, while dry matter and nitrogen-free extract digestibility were maximized in the 9-day fermented treatment.

Conclusion: Urea-assisted fermentation of orange peel meal with *Aspergillus niger* enhances nutrient digestibility without compromising the sensory quality of broiler chicken meat. Fermentation for 9 days is recommended to optimize nutrient utilization efficiency when incorporating orange peel meal into broiler diets.

INTRODUCTION

The persistent increase in the cost of conventional poultry feed ingredients has intensified research efforts toward the utilization of agro-industrial by-products as alternative dietary resources[1]. Orange peels are rich in soluble carbohydrates and various bioactive compounds; however, their application in broiler nutrition remains limited due to their high crude fibre content and low digestibility in monogastric animals[2]. Consequently, improving the nutritive value of orange peel meal through appropriate processing strategies is essential for its effective inclusion in poultry diets[3].

Urea-assisted solid-state fermentation using *Aspergillus niger* has been reported to enhance the nutritional quality of fibrous feed materials through nitrogen enrichment and extensive enzymatic degradation of lignocellulosic components[4]. Extended fermentation periods promote progressive breakdown of structural carbohydrates, thereby improving protein availability and energy utilization[5]. Enhanced nutrient digestibility is closely associated with improved growth performance, carcass characteristics and overall feed efficiency in broiler chickens[6]. Nevertheless, fermentation duration must be carefully optimized, as excessive fermentation may lead to the accumulation of undesirable metabolites that could adversely affect product quality[7].

Meat quality is a critical determinant of consumer acceptance and the economic value of broiler products[8]. Organoleptic attributes, including appearance, flavor, tenderness and juiciness, are influenced by dietary composition and nutrient metabolism[9]. Modifications in feed processing techniques, particularly fermentation duration, may alter muscle composition and lipid profiles, thereby affecting the sensory characteristics of broiler meat[7].

Achieving an optimal balance between enhanced nutrient digestibility and the preservation of desirable sensory qualities is essential for the successful adoption of alternative feed ingredients[3]. Excessive fermentation may result in off-flavors or textural changes due to oxidative processes and alterations in fatty acid composition[6]. Therefore, the present study was conducted to evaluate the effects of fermentation duration of urea-treated fermented orange peel meal on apparent nutrient digestibility and the organoleptic properties of broiler chicken meat.

MATERIALS AND METHODS

Study area: The feeding trial was conducted at the Poultry Unit of the Department of Animal Science Teaching and Research Farm, Ahmadu Bello University, Zaria (ABU), Nigeria. The farm is located at latitude 11°09 N and longitude 7°39 E, with an altitude of about 675 m above sea level[10]. The area experiences distinct dry and wet seasons, with a mean annual rainfall ranging from 700-1,400 mm. The wet season typically commences in late April or early May, peaks between July and August and ends in mid-October, followed by the harmattan period characterized by cool, dry conditions. Average minimum and maximum daily temperatures range from 15.6°C during the cold season to 38.5°C during the hot season. Relative humidity averages approximately 36% during the dry season and 78.5% during the wet season[11].

Collection and processing of orange (*Citrus sinensis*) peels: Fresh orange (*Citrus sinensis*) peels of mixed varieties were collected from orange vendors (locally known as *Mai-lemu*) at Samaru, Sabo and Randa Kano markets in Zaria, Kaduna State. The peels were thoroughly washed with tap water to remove dirt, debris and possible pesticide residues. The cleaned peels were immediately sun-dried at temperatures ranging from 28 to 30°C for three days to reduce moisture content to below 12%. The dried peels were then milled using a hammer mill (Model 912, Winona Attrition Mill Co., USA) fitted with a 2.36 mm (14-mesh) screen. The Resulting Orange Peel Meal (OPM) was stored in nylon-lined polypropylene bags under moisture-free conditions prior to solid-state fermentation.

Enrichment and isolation of *Aspergillus niger*: The enrichment and isolation procedures were carried out at the Microbiology Laboratory, Faculty of Life Sciences, Ahmadu Bello University, Zaria. Cellulolytic *Aspergillus niger* was isolated from spoiled orange samples using an enrichment technique. Tissue segments measuring approximately 3-5 cm were aseptically excised from spoiled oranges using a sterile scalpel and placed on Potato Dextrose Agar (PDA) supplemented with 500 mg streptomycin in Petri dishes. The plates were incubated at room temperature for seven days. Pure cultures obtained were preserved on PDA slants and stored at 4°C. Identification was performed based on microscopic characteristics following the method described by Diba *et al.*[12]. The isolate was further screened for aflatoxin production under ultraviolet light.

Preparation of inoculum: The inoculum was prepared by aseptically transferring a loopful of *A. niger* mycelium into an inoculum medium containing 1% sucrose and 0.2% yeast extract, adjusted to pH 5.50. The culture was incubated aerobically at ambient temperature on a rotary shaker for 24-48 hrs. The resulting spore suspension was standardized to

a concentration of 2.0×10 spores/mL. Spore counts were determined using a haemocytometer (Neubauer-ruled Bright-Line counting chamber; Hausser Scientific, Horsham, PA, USA), with four replicates per count, following the procedure described by Wolk *et al*.[13].

Fermentation procedure: One hundred grams of dried and finely ground OPM were placed in aluminum foil and sterilized by autoclaving. For urea treatment, 1 g of urea was dissolved in 100 mL of sterile water and used to moisten the sterilized OPM, while untreated OPM served as the control substrate. Ten milliliters of the prepared *A. niger* inoculum were added to both urea-treated and untreated OPM. The substrates were transferred into cellophane-covered containers and incubated under anaerobic conditions following the methods of Aro *et al*.[14] and Laconi and Jayanegara[15]. Fermentation was terminated on days 3, 6 and 9, after which the substrates were sun-dried for two days at 28-30°C to inactivate the microorganism. The dried fermented OPM was stored in airtight plastic containers prior to proximate and amino acid analyses.

Pre-experimental operations: Prior to the arrival of the experimental birds, the poultry pens were thoroughly cleaned, washed and disinfected. Fumigation of the pens and surrounding areas was carried out using 40% formaldehyde. The pens were subsequently partitioned into experimental units and labeled according to dietary treatments and replicates.

Ethical clearance: Ethical approval for the use of experimental animals was obtained from the Ahmadu Bello University Committee on Animal Use and Care (ABUCAUC) before the commencement of the study (Approval No. ABUCAUC/2023/147).

Dietary treatments: Experimental diets were formulated to meet the nutrient requirements of broiler chickens in accordance with NRC recommendations[16]. Fermented Urea-treated Orange Peel Meal (FUTOPM) was incorporated into the diets at a 20% inclusion level. The ingredient composition of the starter and finisher diets was balanced to ensure that the diets were isonitrogenous and isocaloric, as presented in Table 1 and 2, respectively.

Experimental design and management of birds: A total of two hundred and forty (240) day-old Arbor Acre broiler chicks of mixed sexes were procured from Dahmas Hatchery, Ibadan, Oyo State, Nigeria. The birds were randomly assigned to 4 dietary treatments comprising a control diet and diets containing 20% fermented urea-treated orange peel meal (FUTOPM) subjected to 3-, 6- and 9-day fermentation periods. Each treatment consisted of 4 replicates, with 15 birds per replicate.

Initial body weights of the birds within each replicate were equalized (±1 g) using a 10 kg Camry digital weighing scale (4th generation model, Taiwan). Thereafter, birds were provided ad libitum access to their respective experimental diets and clean drinking water throughout the feeding period. The feeding trial lasted for 8 weeks. All birds were housed in deep-litter pens at the Department of Animal Science Teaching and Research Farm (T and RF), Ahmadu Bello University, Zaria and managed under standard husbandry practices, including electrical brooding during the brooding phase.

The starter diets were formulated to be isonitrogenous (23% crude protein) and isocaloric (2,900 kcal/kg metabolizable energy), as presented in Table 1. Birds were vaccinated in accordance with recommended vaccination schedules following standard poultry health management protocols. The experiment was arranged in a Completely Randomized Design (CRD).

Data collection

Organoleptic study: Meat samples for palatability assessment were obtained from the breast and thigh muscles of the birds. Meat preparation was carried out using the wet cooking method as described previously[17]. Cooked samples were served to 30 semi-trained panelists who were instructed to evaluate samples from each dietary treatment and score them for appearance, flavor, texture, juiciness, tenderness and overall acceptability.

To minimize carryover effects, potable water was provided to panelists for mouth rinsing between sample evaluations. Sensory attributes were scored using a 9-point hedonic scale, where 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much and 9 = like extremely, following the procedures outlined by Sanwo *et al*.[18] and Kyakma *et al*.[19].

Meat oxidation analysis

Lipid peroxidation (malondialdehyde): Lipid peroxidation was assessed by determining malondialdehyde (MDA) concentration using the modified method of Niehaus and Samuelson[20], as described by Akanji *et al*.[21].

Table 1: Ingredients composition and proximate composition of broiler starter diets containing fermented urea treated orange peel meal (0-4 weeks)

	Fermentation duration			
	FUTOPM (20%)			
Ingredients	Control	3-days	6-days	9-days
Maize	56.80	39.40	38.20	37.50
Soybean meal	29.00	29.00	29.00	29.00
Groundnut cake	10.00	7.00	8.60	9.30
FUTOPM	0.00	20.00	20.00	20.00
Lysine	0.10	0.10	0.10	0.10
Methionine	0.20	0.20	0.20	0.20
Bone Meal	3.00	3.00	3.00	3.00
Limestone	0.40	0.40	0.40	0.40
Vit/Min Premix[1]	0.25	0.25	0.25	0.25
Salt	0.25	0.25	0.25	0.25
Total	100.00	100.00	100.00	100.00
Calculated analysis				
ME (kcal/kg) DM	2963.20	2947.73	2993.45	2957.28
Crude protein (%)	23.00	23.00	23.00	23.00
Ether extract (%)	3.23	3.23	3.23	3.23
Crude fibre (%)	3.52	3.60	3.62	3.63
Calcium (%)	1.31	1.31	1.31	1.31
Phosphorus (%)	0.87	0.87	0.87	0.87
Lysine (%)	1.26	1.26	1.26	1.26
Met.+Cys. (%)	0.55	0.55	0.55	0.55
Cost (N/kg)	772.79	755.24	737.79	730.58
Proximate composition				
Dry matter (%)	90.66	89.62	87.29	88.61
Crude protein (%)	21.71	21.53	22.82	23.37
Ash (%)	7.90	10.42	9.04	12.04
Crude fibre (%)	5.73	5.30	4.36	5.79
Ether extract (%)	7.58	8.06	7.33	5.54
Nitrogen free extract	76.27	68.33	75.86	81.58

FUTOPM: Fermented urea treated orange peel meal, ME: Metabolizable energy, Met: Methionine, Cys: Cysteine, [1]Vitamin/Mineral Premix (Bio-mix®) Each 2.5kg supplied, Vit A: 10,000,000 iu, Vit D_3: 2,000,000 iu; Vit E: 23,000 mg, Vit K_3: 2,000mg, Vit B_1: 1,800 mg, Vit B_2: 5,500 mg, Niacin: 27,500 mg, Pantothenic acid: 7,500 mg, Vit B_6: 3,000 mg, Vit B_{12}: 15 mg, Folic acid: 750 mg, Biotin: 60 mg, Choline Chloride: 300,000 mg; Cobalt: 200 mg, Copper: 3,000 mg, Iodine: 1,000 mg. Iron: 20,000 mg, Manganese: 40,000 mg, Selenium: 200 mg, Zinc: 30,000 mg and Antioxidant: 1,250 mg

Table 2: Ingredients composition of broiler finisher diets containing fermented urea treated orange peel meal (5-8 weeks)

	Fermentation duration			
	FUTOPM (20%)			
Ingredients	Control	3-days	6-days	9-days
Maize	58.00	41.30	40.00	39.40
Wheat Bran	7.00	7.00	7.00	7.00
Soybean meal	21.00	21.00	21.00	21.00
Groundnut cake	9.80	6.50	7.80	8.40
FUTOPM	0.00	20.00	20.00	20.00
Lysine	0.10	0.10	0.10	0.10
Methionine	0.20	0.20	0.20	0.20
Bone Meal	3.00	3.00	3.00	3.00
Limestone	0.40	0.40	0.40	0.40
Vit/Min Premix[1]	0.25	0.25	0.25	0.25
Salt	0.25	0.25	0.25	0.25
Total	100.00	100.00	100.00	100.00
Calculated analysis				
ME (Kcal/kg) DM	3100.36	3118.48	3120.30	3122.29
Crude Protein (%)	20.00	20.00	20.00	20.00
Ether Extract (%)	3.53	3.53	3.53	3.53
Crude Fibre (%)	3.91	3.91	3.91	3.91

Table 2: Continue

	Fermentation duration			
	FUTOPM (20%)			
Ingredients	Control	3-days	6-days	9-days
Calcium (%)	1.29	1.29	1.29	1.29
Phosphorus (%)	0.85	0.85	0.85	0.85
Lysine (%)	1.02	1.02	1.02	1.02
Met.+Cys. (%)	0.50	0.50	0.50	0.50
Cost (N/kg)	718.04	700.54	683.04	678.54
Proximate composition				
Dry matter (%)	87.33	86.38	88.85	89.87
Crude protein (%)	20.38	18.29	20.38	20.49
Ash (%)	6.39	7.26	5.20	3.17
Crude fibre (%)	4.38	3.57	7.93	6.39
Ether extract (%)	5.37	4.29	5.68	6.83
Nitrogen free extract	67.74	78.19	89.22	85.93

FUTOPM: Fermented Urea Treated Orange Peel Meal, ME: Metabolizable Energy, Met: Methionine, Cys: Cysteine, [1]Vitamin/Mineral Premix (Bio-mix®) Each 2.5 kg supplied, Vit A: 8,500,000 iu, Vit D_3 1:500,000 iu, Vit E: 10,000 mg, Vit K_3: 1,500 mg, Vit B_1: 1,600 mg, Vit B_2: 4,000 mg, Niacin: 20,000 mg, Pantothenic acid: 5,000 mg, Vit B_6: 1,500 mg, Vit B_{12}: 10mg, Folic acid: 500 mg; Biotin: 50 mg, Choline Chloride: 175,000 mg, Cobalt: 200 mg, Copper: 3,000 mg, Iodine: 1,000 mg, Iron: 20, 000 mg, Manganese: 40,000 mg, Selenium: 200 mg, Zinc: 30,000 mg and Antioxidant: 1,250 mg

Digestibility trial: Following the 56-day feeding trial, a nutrient digestibility study was conducted. Birds were allowed a 3 day acclimatization period, after which 1 bird was randomly selected from each replicate pen, resulting in 4 birds per treatment. Selected birds were transferred to individual, clean and disinfected metabolic cages fitted with wire-mesh floors. Polythene sheets were placed beneath each cage to facilitate total fecal collection.

Each bird was offered a known quantity (1,500 g) of the experimental diet, representing the average daily feed intake of birds in the respective treatment groups, during the acclimatization period. Feed intake was determined by weighing feed refusals daily and subtracting them from the quantity offered. Clean drinking water was provided ad libitum throughout the digestibility trial.

Total fecal collection was carried out for 5 consecutive days. Collected excreta were oven-dried at the Product Development Research Programme (PDRP) Laboratory, Institute for Agricultural Research (IAR), Zaria. Extraneous materials were carefully removed, after which the samples were sun-dried and analyzed for proximate composition, including dry matter, crude protein, crude fiber, ether extract, ash and nitrogen-free extract, in the Nutrition Laboratory, Institute for Agricultural Research, Zaria, using standard AOAC methods[22].

The percentage coefficient of digestibility was calculated using the equation below:

$$\text{Coefficient of digestibility (\%)} = \frac{\text{Nutrient intake-nutrient output}}{\text{Nutrient intake}} \times 100$$

Where:

Nutrient Intake (g) : Feed Intake × Nutrient in diet

Nutrient Output (g) : Faecal Output × Nutrient in faeces

Data analysis: All data collected were subjected to the General Linear Model (GLM) procedure of SAS[23]. Significant differences among treatment means were determined using Duncan's Multiple Range Test[24]. Statistical significance was declared at $p<0.05$.

RESULTS AND DISCUSSION

Table 3 presents the organoleptic properties of meat obtained from broiler chickens fed diets containing a 20% inclusion level of Fermented Urea-treated Orange Peel Meal (FUTOPM) subjected to different fermentation durations. No significant differences ($p>0.05$) were observed among treatments for appearance, flavor, texture, juiciness, tenderness, or overall acceptability. These findings indicate that the inclusion of FUTOPM, irrespective of fermentation duration, did not adversely affect the sensory quality of broiler chicken meat. Similar observations were reported by Sun *et al.*[25], who demonstrated that urea-treated fermented plant-based feedstuffs did not compromise meat palatability in broiler chickens, suggesting that fermentation improves digestibility without altering sensory attributes.

However, the present results are not entirely consistent with the findings of Idrissa *et al.*[26], who reported that moderate urea fermentation of agro-industrial by-products enhanced protein digestibility, resulting in improved meat

Table 3: Organoleptic properties of meat from broiler chicken fed diets containing 20% inclusion level of FUTOPM at varying fermentation periods

	Dietary treatment					
Parameters	Control	3-days	6-days	9-days	SEM	p-value
Appearance	6.13	5.87	6.27	5.73	0.72	0.99
Flavour	6.20	5.93	6.30	5.70	0.72	0.99
Texture	6.97	6.33	6.30	6.07	0.72	0.97
Juiciness	5.77	5.70	6.13	6.07	0.72	0.10
Tenderness	6.13	6.70	6.13	6.47	0.72	0.99
Overall acceptability	5.80	6.10	6.33	6.00	0.72	0.10

SEM: Standard error of mean and FUTOPM: Fermented urea treated orange peel meal

Table 4: Oxidative activity of meat from broiler chickens fed diets containing 20% inclusion level of FUTOPM at varying fermentation periods

	Dietary treatment					
Parameters (µmol/mg protein)	Control	3-days	6-days	9-days	SEM	p-value
Malondialdehyde (MDA)	14.65^{c}	11.64^{b}	10.73^{ab}	9.60^{a}	0.30	0.02
Glutathione peroxide (GPx)	24.79^{c}	36.05^{ab}	33.76^{b}	37.47^{a}	0.49	0.01

^{abc}Means on the same row with different superscript are significantly different ($p<0.05$) SEM: Standard error of mean and FUTOPM: Fermented urea treated orange peel meal

tenderness and overall acceptability. Conversely, the findings of the present study align with those of Sun *et al.*[25], who observed that broiler meat quality remained unchanged when urea-treated fermented diets were incorporated at moderate inclusion levels.

Table 4 summarizes the oxidative stability indices of meat from broiler chickens fed diets containing 20% FUTOPM at varying fermentation durations. Malondialdehyde (MDA) concentration was significantly lower ($p<0.05$) in meat from birds fed the 9-day FUTOPM diet (9.60 µmol/mg protein), followed by those fed the 6-day (10.73 µmol/mg protein) and 3-day (11.64 µmol/mg protein) FUTOPM diets, while the highest MDA level was observed in the control group (14.65 µmol/mg protein). Meat from birds fed the 6-day FUTOPM diet was statistically comparable ($p>0.05$) to that from the 3-day fermentation group.

Glutathione Peroxidase (GPx) activity was significantly higher ($p<0.05$) in meat from birds fed the 9-day FUTOPM diet (37.47 µmol/mg protein), followed by those fed the 3-day (36.05 µmol/mg protein) and 6-day (33.76 µmol/mg protein) FUTOPM diets, whereas the lowest GPx activity was recorded in the control group (24.79 µmol/mg protein). GPx activity in meat from birds fed the 3-day FUTOPM diet was statistically similar ($p>0.05$) to that observed in the 9-day FUTOPM group. The observed variations in MDA concentration and GPx activity indicate that fermentation duration plays a critical role in modulating meat oxidative stability. Comparable results were reported by Zhao *et al.*[27], who demonstrated that urea-treated fermented agro-industrial by-products reduced lipid peroxidation in poultry meat by enhancing antioxidant activity. Malondialdehyde, a key biomarker of lipid peroxidation and oxidative damage, was highest in meat from birds fed the control diet, indicating increased susceptibility to oxidative degradation. The significantly lower MDA levels observed in meat from birds fed the 6-day and 9-day FUTOPM diets suggest that extended fermentation enhances oxidative stability.

These findings are consistent with the report of Mahfuz *et al.*[28], who indicated that fermentation generates bioactive compounds, including polyphenols and flavonoids, which mitigate oxidative damage in broiler chicken meat. The presence of such antioxidant compounds likely contributed to the reduced lipid peroxidation observed in the longer fermentation treatments. Furthermore, the significantly elevated GPx activity in meat from birds fed the 9-day FUTOPM diet suggests an enhanced antioxidant defense system. The increased GPx levels may be attributed to improved bioavailability of antioxidant precursors generated during fermentation, as reported by Xu *et al.*[29], who demonstrated that enzymatic degradation of anti-nutritional factors during urea fermentation enhances the synthesis of antioxidant enzymes and improves meat oxidative stability.

Overall, the results indicate that dietary inclusion of FUTOPM, particularly when fermented for 6 to 9 days, improves the oxidative stability of broiler chicken meat without compromising sensory quality. These findings corroborate earlier reports by Sun *et al.*[25], who demonstrated that fermentation enhances the functional properties of feed ingredients, leading to improved oxidative stability in broiler chicken meat.

Table 5 presents the apparent nutrient digestibility of broiler chickens fed diets containing a 20% inclusion level of fermented urea-treated orange peel meal (FUTOPM) subjected to varying fermentation durations. Crude protein digestibility was significantly higher ($p<0.05$) in birds fed the 3-day (92.67%), 6-day (91.08%) and 9-day (92.45%) FUTOPM diets

Table 5: Apparent nutrient digestibility of broiler chicken fed diets containing 20% inclusion level of FUTOPM at varying fermentation periods

	Dietary treatment					
Parameters	Control	3-days	6-days	9-days	SEM	p-value
Dry matter (%)	85.70^{ab}	80.64^{ab}	80.22^{b}	86.14^{a}	0.86	0.02
Crude protein (%)	85.91^{b}	92.67^{a}	91.08^{a}	92.45^{a}	0.48	0.01
Crude fibre (%)	84.35^{bc}	81.35^{c}	86.55^{ab}	90.27^{a}	0.71	0.01
Ether extract (%)	87.24^{b}	92.15^{a}	88.28^{b}	87.42^{b}	0.59	0.04
Nitrogen free extract (%)	82.63^{ab}	79.04^{b}	86.81^{a}	87.59^{a}	0.79	0.01

^{abc}Means on the same row with different superscripts are significantly different (p<0.05), SEM: Standard error of mean, FUTOPM: Fermented urea treated orange peel meal

compared with those fed the control diet (85.91%). Crude fibre digestibility was significantly (p<0.05) highest in birds fed the 9-day FUTOPM diet (90.27%), followed by those fed the 6-day FUTOPM diet (86.55%), the control diet (84.35%) and the 3-day FUTOPM diet (81.35%), with birds on the control and 6-day FUTOPM diets being statistically similar (p>0.05).

Ether extract digestibility was significantly higher (p<0.05) in birds fed the 3-day FUTOPM diet (92.15%) than in those fed the control diet (87.24%), the 6-day FUTOPM diet (88.28%) and the 9-day FUTOPM diet (87.42%), which did not differ significantly from one another (p>0.05). Nitrogen-free extract digestibility was significantly higher (p<0.05) in birds fed the 9-day (87.59%) and 6-day (86.81%) FUTOPM diets compared with those fed the 3-day FUTOPM diet (79.04%), while values for the control diet (82.63%) were statistically comparable (p>0.05) to those observed for the 6-day and 9-day FUTOPM diets. Dry matter digestibility was significantly higher (p<0.05) in birds fed the 9-day FUTOPM diet than in those fed the 6-day FUTOPM diet but did not differ significantly from values recorded for the 3-day FUTOPM and control diets.

These results demonstrate that fermentation improved nutrient digestibility in broiler chickens, with the 9-day fermented diet exhibiting the highest digestibility for most measured parameters. The findings are consistent with earlier reports highlighting the benefits of incorporating fermented feed ingredients into poultry diets. Chiang *et al.*[30] reported that broiler chickens fed diets containing 10% solid-state fermented rapeseed meal exhibited significantly improved nutrient digestibility compared with those fed unfermented meals. Similarly, Diarra[31] noted that high fibre content and the presence of antinutritional factors in agro-industrial by-products may limit their nutritional efficiency if not adequately processed.

The use of urea-treated orange peel meal in the present study is particularly noteworthy, as urea treatment has been shown to enhance the nutritional value of high-fibre feed ingredients by facilitating the breakdown of complex structural carbohydrates and reducing antinutritional factors, thereby improving nutrient availability and digestibility[31]. However, caution is warranted regarding the use of urea in poultry nutrition. Unlike ruminants, poultry lack the gastrointestinal microbial capacity required to efficiently convert non-protein nitrogen sources, such as urea, into utilizable protein. Consequently, the direct inclusion of urea in poultry diets has been approached with caution due to potential toxicity concerns[32]. In the present study, urea was applied during the pre-fermentation treatment of orange peel meal rather than being directly incorporated into the diets, which likely mitigated potential adverse effects by reducing antinutritional factors and enhancing nutrient bioavailability.

CONCLUSION

The present study demonstrated that dietary inclusion of urea-treated fermented orange peel meal, irrespective of fermentation duration, preserved the sensory quality of broiler chicken meat while significantly enhancing the apparent digestibility of crude protein, crude fiber, ether extract and other nutrients. The most pronounced improvements in nutrient utilization were observed in birds fed the 9-day fermented diet. These findings confirm the effectiveness of combining urea treatment with extended fermentation in mitigating the nutritional limitations associated with raw orange peel meal and improving overall feed efficiency. Furthermore, this approach provides a practical and sustainable strategy for valorizing citrus agro-industrial waste into a high-quality feed ingredient for poultry production. Based on the observed improvements in nutrient digestibility and oxidative stability without compromising meat palatability, a 9-day fermentation period is recommended for feed manufacturers seeking to maximize nutrient recovery and promote environmentally sustainable poultry production systems.

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