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Effects of sardine head by-products from fish cracker (keropok) processing on the productive performance and feed production costs of Thai native crossbred chickens

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Abstract This study investigated the effects of sardine head by-products from fish cracker (keropok) processing in the diet upon the productive performance and feed production costs of Thai native crossbred chickens over a 12-week period. Results indicated that the inclusion of the sardine head by-product significantly enhanced body weight gain and feed efficiency across all growth phases. The highest inclusion level (1.5%) yielded the most superior final body weight (2,472 g) and the lowest total feed conversion ratio (2.339), while maintaining a 100% survival rate throughout the latter half of the trial. Moreover, substituting sardine head by-products in the diet (up to 1.5%) are significantly lowers feed production costs and improved feed efficiency across all growth stages. The 1.5% inclusion rate (T4) proved most economical, reducing total costs by 4.69 baht/kg over 12 weeks. These findings are suggested that sardine head by-products are an effective and safe alternative protein source for optimising the productivity and feed production costs of Thai native crossbred chickens.

Keywords: Sardine head by-product, Productive performance, Feed production costs, Thai native crossbred chickens

Introduction

Nowadays, the commercial production of native chickens has been increasing in relevance due to the increased demand for natural and organic meat (Bai *et al*., 2022). Consumers prefer tasty and healthy foods with naturally bioactive ingredients. Native breeds contain higher quantities of peptide proteins, fatty acids, and antioxidants, making poultry flesh commonly consumed (Tunim

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et al., 2021). Additionally, Thai native chickens have been shown to have low fat and high meat quality (Jaturasitha *et al*., 2008). Another researcher reported that people consume chicken meat in large quantities because of its low to medium fat level. Chicken flesh is a popular protein source due to its comparatively low-fat content. Unsaturated fatty acids, such as the omega-3 (n-3) and omega-6 (n-6) fatty acids, make up around two-thirds of poultry fat. One possible tactic to lessen inflammatory and cardiovascular disorders is the creation of meat products with higher quantities of unsaturated fatty acids, especially n-3 fatty acids, and lower fat content (Kris-Etherton and Harris, 2002; Ruxton, 2007). Wattanachant *et al*. (2004) reported that native chickens are produced using a minimal input and high output approach that is primarily limited to backyard rearing. Additionally, the development of local chickens is critical since they are one of the primary sources of animal protein for the population (Ralahalu *et al*., 2021). They are raised in backyard farms with poor husbandry practices, little nourishment, and scorching conditions. Genetic constraints in local hens can result in low productivity in terms of growth rate and egg output. In many nations, indigenous chicken breeds are crucial for sustaining rural economies. They possess key advantages, including inherent disease resistance and a notable capacity for environmental adaptation, which collectively contribute to their ability to yield superior meat and eggs (Dudung, 1990). Nevertheless, there is not enough supply to satisfy customer demand because of their limited growth rate and low egg output (Chomchuen *et al*., 2022).

Thai native chicken production on a commercial scale is limited due to slow growth rates, poor performance, and high costs, requiring 65–70% feedstuff and the use of commercial feeds (Kridtayopas *et al*., 2019; Adugna *et al*., 2020). To reduce expenses, native chicken production could be localised, such as by using by-products from the fish processing industry. Ideia *et al*. (2020) claimed that the fish processing industry has grown significantly and is now a major contributor to the global economy. The increased exploration of marine resources produces a significant amount of biowaste, which ultimately is typically discarded. Numerous attempts have been undertaken to address the fisheries waste with more effective methods due to the ensuing disposal and environmental issues. These by-products are now recognised as significant sources of high-value substances with strong potential for use in human health, since they contain hydroxyapatite, collagen, gelatine, lipids, enzymes, hydrolysates, and bioactive peptides.

The objectives were, to determine the effects of the dietary inclusion of sardine head residue, a by-product of keropok processing, on the productive performance, and to evaluate the associated feed costs of Thai native crossbred chickens.

Materials and methods

Code of conduct for laboratory animals

This research was co-operated by the Institutional Animal Care and Committee, Princess of Naradhiwas University, Thailand No. PNU.AE-2025/01.008.

Preparation of sardine head by-products

The sardine head by-products were brought from keropok (kuepo) production at Mueang district, Narathiwat province, Thailand. They were cleaned and sun-dried for 2 days. They were then dried in a hot air oven at 65°C for three days. The dried fish head residues were mechanically crushed into powder with an electric grinder and sieved through a 1-millimetre filter to guarantee uniform particle size. The resulting powder was stored in glass bottles and refrigerated at 4°C until used in the experiment.

Animal experimentation and management

A completely randomised design (CRD) was employed using 240 mixed-sex, one-day-old commercial Thai native chicks. Four dietary treatments containing 0%, 0.5%, 1.0%, and 1.5% fish head residue meal were tested, with four replicates of 15 birds each. The trial covered three growth phases (1–4, 5–8, and 9–12 weeks). The formulation and nutrient composition of the diets are presented in Tables 1–3. Feed and drinking water were available *ad libitum* throughout the experimental period. Routine management practices, including vaccination and health monitoring, were carried out according to standard poultry husbandry guidelines.

Data collection

Productive performance

This study was carried out on Thai native chickens to assess their productive performance. Data were collected on feed intake (FI), live body weight (LBW), body weight increase (BWG), feed conversion ratio (FCR), and survival rate.

Table 1. Feed composition and nutrient contents for Thai native chickens from 1-4 weeks of age

Ingredients	**Treatment Groups**			
	T1	**T2**	**T3**	**T4**
Corn	59.6	57.3	56.0	57.3
Soybean meal	24.0	27.0	27.0	27.0
Fish meal	7.2	7.0	7.3	6.0
Sardine head by-product[1]	0.0	0.5	1.0	1.5
Palm oil	4.0	3.5	3.5	3.0
Dicalcium phosphate	2.1	2.1	2.1	2.1
Shell	1.3	1.3	1.3	1.3
Salt	0.3	0.3	0.3	0.3
L-Lysine	0.5	0.5	0.5	0.5
DL-Methionine	0.5	0.5	0.5	0.5
Premix[2]	0.5	0.5	0.5	0.5
Total	**100**	**100**	**100**	**100**
Cost /Kg	**13.52**	**13.39**	**13.35**	**13.30**
Analysed chemical composition (% air - dry basis)				
Metabolisable energy (ME, Kcal/Kg)	3,001	3,052	3,076	3,068
Crude protein	21.30	21.44	21.35	21.40
Crude fat	6.17	6.26	6.35	6.17
Crude fiber	3.72	3.74	3.72	3.72
Ash	7.34	7.45	7.48	7.49
Calcium	1.64	1.66	1.65	1.64
Available phosphorus	0.58	0.54	0.59	0.58
Lysine	1.37	1.38	1.37	1.37
Methionine	0.47	0.47	0.47	0.47

[1]Sardine head by-product from fish cracker processing in powder form;[2]Vitamins and Minerals: vit A, D 0.15 g.; vit E 50g. vit K_3 50 0.01g., vit B_1 0.01g., vit B_2 0.002g., vit B_6 0.03g, vit B_{12} 0.22g, Biotin 0.00025g., Folic acid 0.00025g., Niacin 0.10g., Pantothenic acid 0.022g., Selenium 0.60 g., Choline chloride 0.095 g., Fe 1.185 mg., Zn 0.35 mg;T1: control diet + 0% sardine head by-product powder, T2: control + 0.5% sardine head by-product powder, T3: control + 1.0% sardine head by-product powder, T4: control + 1.5% sardine head by-product powder

Table 2. Feed composition and nutrient contents for Thai native chickens from 5-8 weeks of age

Ingredients	**Treatment Groups**			
	T1	**T2**	**T3**	**T4**
Corn	60.0	61.1	61.1	61.0
Soybean meal	27.0	27.0	27.0	27.0
Fish meal	4.0	3.2	2.7	2.3
Sardine head by-product[1]	0.0	0.5	1.0	1.5
Palm oil	3.0	3.0	3.0	3.0
Dicalcium phosphate	2.1	2.1	2.1	2.1
Shell	1.3	1.3	1.3	1.3
Salt	0.3	0.3	0.3	0.3
L-Lysine	0.5	0.5	0.5	0.5
DL-Methionine	0.5	0.5	0.5	0.5
Premix[2]	0.5	0.5	0.5	0.5
Total	**100**	**100**	**100**	**100**
Cost /Kg	**13.36**	**12.86**	**12.78**	**12.72**
Analysed chemical composition (% air - dry basis)				
Metabolisable energy (ME, Kcal/Kg)	3,063	3,021	3,037	3,041
Crude protein	19.50	19.58	19.56	19.58
Crude fat	5.59	6.00	6.17	6.18
Crude fiber	3.50	3.36	3.27	3.20
Ash	7.39	8.07	8.10	8.13
Calcium	1.44	1.39	1.46	1.48
Available phosphorus	0.51	0.54	0.58	0.59
Lysine	1.18	1.18	1.19	1.19
Methionine	0.47	0.42	0.43	0.45

[1]Sardine head by-product from fish cracker processing in powder form;[2]Vitamins and Minerals: vit A, D 0.15 g.; vit E 50g. vit K_3 50 0.01g., vit B_1 0.01g., vit B_2 0.002g., vit B_6 0.03g, vit B_{12} 0.22g, Biotin 0.00025g., Folic acid 0.00025g., Niacin 0.10g., Pantothenic acid 0.022g., Selenium 0.60 g., Choline chloride 0.095 g., Fe 1.185 mg., Zn 0.35 mg, T1: control diet + 0% sardine head by-product powder, T2: control + 0.5% sardine head by-product powder, T3: control + 1.0% sardine head by-product powder, T4: control + 1.5% sardine head by-product powder

Table 3. Feed composition and nutrient contents for Thai native chickens from 9-12 weeks of age

Ingredients	**Treatment Groups**			
	T1	**T2**	**T3**	**T4**
Corn	66.8	66.3	66.3	66.3
Soybean meal	23.0	23.0	22.5	22.0
Fish meal	2.0	2.0	2.0	2.0
Sardine head by-product[1]	0.0	0.5	1.0	1.5
Palm oil	3.0	3.0	3.0	3.0
Dicalcium phosphate	2.1	2.1	2.1	2.1
Shell	1.3	1.3	1.3	1.3
Salt	0.3	0.3	0.3	0.3
L-Lysine	0.5	0.5	0.5	0.5
DL-Methionine	0.5	0.5	0.5	0.5
Premix[2]	0.5	0.5	0.5	0.5
Total	**100**	**100**	**100**	**100**
Cost /Kg	**12.48**	**12.47**	**12.43**	**12.39**
Analysed chemical composition (% air - dry basis)				
Metabolisable energy (ME, Kcal/Kg)	3,066	3,074	3,087	3,100
Crude protein	17.34	17.56	17.60	17.64
Crude fat	6.17	6.17	6.16	6.16
Crude fiber	3.72	3.71	3.71	3.72
Ash	7.81	7.88	7.89	8.06
Calcium	1.64	1.65	1.66	1.6697
Available phosphorus	0.58	0.57	0.55	0.56
Lysine	1.18	1.24	1.24	1.26
Methionine	0.45	0.46	0.45	0.45

[1]Sardine head by-product from fish cracker processing in powder form;[2]Vitamins and Minerals: vit A, D 0.15 g.; vit E 50g. vit K_3 50 0.01g., vit B_1 0.01g., vit B_2 0.002g., vit B_6 0.03g, vit B_{12} 0.22g, Biotin 0.00025g., Folic acid 0.00025g., Niacin 0.10g., Pantothenic acid 0.022g., Selenium 0.60 g., Choline chloride 0.095 g., Fe 1.185 mg., Zn 0.35 mg, T1: control diet + 0% sardine head by-product powder, T2: control + 0.5% sardine head by-product powder, T3: control + 1.0% sardine head by-product powder, T4: control + 1.5% sardine head by-product powder

Statistical analysis

One-way analysis of variance (ANOVA) was analysed all the data. Duncan's Multiple Range Test (DMRT) wascompared the means. The UNIVARIATE procedure of SAS software (SAS, 2017) was used to compare the descriptive statistics.

Results

Productive performance

The study investigated the effects of incorporating sardine head by-product powder into the diets of Thai native chickens across four developmental stages: starter, grower, finisher, and the total production period. The experimental design utilised a control group (T1) and three treatment levels of sardine head by-product: 0.5% (T2), 1.0% (T3), and 1.5% (T4). The data found that the inclusion of this by-product significantly influenced growth performance and feed efficiency, particularly at higher concentrations.

During the starter period (1–4 weeks of age), the inclusion of sardine head by-product significantly improved the most productive performance compared to the control group (T1). T2, T3, and T4 exhibited significantly higher final body weight (ranging from 460.46 to 465.66 g/b) and body weight gain (ranging from 412.75 to 418.14 g/b) compared to T1 (423.64 g/b and 376.19 g/b, respectively). Cumulative feed intake was lowest for T1 (834.10 g/b) and highest for T4 (875.79 g/b), showing a significant difference across the groups. Crucially, the T1 control group had a significantly worse feed conversion ratio (FCR) (2.218) compared to the supplemented groups (T2 at 2.051, T3 at 2.078, and T4 at 2.123), indicating that the sardine head by-product diets were used more efficiently to gain weight. Additionally, survival rates were high and did not differ significantly between the groups (98.75% to 100%).

In the grower period (5–8 weeks of age), the positive trends generally continued. Group T4 achieved the highest final body weight (1,409.69 g/b), which was significantly higher than T1 (1,257.19 g/b) but not significantly different from T2 (1,361.25 g/b) or T3 (1,363.13 g/b). Body weight gain also followed this pattern, with T4 having the highest gain (768.10 g/b), although the differences across all groups were not statistically significant. Treatment groups (T2, T3, and T4) had significantly higher cumulative feed intake compared to the control group (T1). For FCR and survival rate, similar to the starter phase, the differences in FCR and survival rate during the grower period were not statistically significant among the treatments. The trend for FCR, however, suggested T4 was the most efficient (2.63), while T1 was the least (2.87).

During the finisher period (9–12 weeks of age), the inclusion of sardine head by-product powder exerted its most profound impact on growth performance and feed efficiency. The T4 group (1.5% inclusion) achieved the highest final body weight of 2,472.00 g and a body weight gain of 1,062.31 g, both of which were significantly superior to the control (T1) and lower-inclusion groups. While cumulative feed intake was significantly higher for all treatment

groups compared to the control, the efficiency of nutrient utilisation improved linearly with higher concentrations of the by-product; the feed conversion ratio (FCR) for T4 was markedly optimised at 2.63 compared to 3.27 in the control group. Furthermore, health remained optimal during this final stage, with all experimental groups maintaining a 100% survival rate.

For the total duration of the study (1–12 weeks of age), the cumulative results demonstrate that dietary supplementation with sardine head by-product powder significantly enhances the overall productivity of Thai native chickens. By the conclusion of the 12-week trial, the T4 group (1.5% inclusion) attained a final body weight of 2,472.00 g, which was significantly higher than the T3/T2 groups and the control group's 2,035.83 g. Total body weight gain followed a similar trajectory, with T4 birds gaining significantly more mass (2,424.29 g) than those in the control group (1,988.39 g). While the treated groups exhibited higher cumulative feed intake compared to the control, they were substantially more efficient at converting that feed into body mass; the total feed conversion ratio (FCR) was significantly improved at 2.339 for T4 compared to 2.635 for the control group. Throughout the entire 12-week period, survival rates remained high and statistically similar across all groups, ranging from 99.38% to 100.00%, confirming the safety of the dietary inclusion levels.

Beyond growth measures, the study found that sardine head by-product is safe to consume and has no negative impact on bird health. Survival rates were consistently high across all treatments throughout the research, with no statistically significant differences between groups ($P > 0.05$). Notably, the T4 group had a 100% survival rate during the finisher and total phases, implying that a 1.5% inclusion level is both extremely beneficial for growth and safe for the physiological well-being of Thai native chickens.

Production cost

The study investigated the effect of incorporating sardine head by-products from fish cracker processing into the diets of Thai native chickens, focusing on production costs across three distinct growth stages: starter (1–4 weeks of age), grower (5–8 weeks of age), and finisher (9–12 weeks of age). The experimental design utilised four groups (T1–T4), where T1 served as the control group. Key performance indicators analysed included feed per body weight gain (FCR), feed cost per kilogram, and overall production cost per kilogram.

Table 4. Productive performance of Thai native chickens, 1-4, 5-8, 5-12, and 1-12 weeks old, fed diets containing varying levels of sardine head by-product from fish cracker (keropok) processing

Productive performance	Experimental groups				SEM	P-value
	T1	T2	T3	T4		
Initial body weight (g/bird)	47.44	47.88	47.52	47.71	0.42	0.8853
Starter period (1-4 weeks of age):						
Final body weight (g/bird)	423.64^{b}	463.31^{a}	465.66^{a}	460.46^{a}	0.81	0.0005
Body weight gain (g/bird)	376.19^{b}	415.43^{a}	418.14^{a}	412.75^{a}	0.82	0.0006
Cumulative feed intake (g/bird)	834.10^{c}	851.94^{bc}	867.89^{ab}	875.79^{a}	0.95	0.0035
Feed conversion ratio	2.218^{a}	2.051^{b}	2.078^{b}	2.123^{b}	0.004	0.0078
Survival rate (%)	98.75	99.52	99.52	100.00	0.07	0.3916
Grower period (5-8 weeks of age):						
Final body weight (g/bird)	1,257.19^{b}	1,361.25^{ab}	1,363.13^{ab}	1,409.69^{a}	5.15	0.0556
Body weight gain (g/bird)	662.60	723.69	718.41	768.10	5.47	0.3089
Cumulative feed intake (g/bird)	1,870.59^{b}	1,973.53^{a}	1,958.27^{a}	1,999.78^{a}	2.69	0.0019
Feed conversion ratio	2.87	2.73	2.73	2.63	0.02	0.7403
Survival rate (%)	99.37	99.48	99.48	100.00	0.07	0.7961
Finisher period (9-12 weeks of age):						
Final body weight (g/b)	2,035.83^{c}	2,295.17^{b}	2,347.50^{b}	2,472.00^{a}	4.83	<0.0001
Body weight gain (g/bird)	778.65^{c}	933.92^{b}	984.38^{ab}	1062.31^{a}	4.98	0.0004

Cumulative feed intake (g/bird)	2,531.96^{b}	2,788.48^{a}	2,804.16^{a}	2,794.21^{a}	7.72	0.0061
Feed conversion ratio	3.27^{a}	2.98^{ab}	2.86^{bc}	2.63^{c}	0.01	0.0030
Survival rate (%)	100.00	100.00	100.00	100.00	-	-
Total period (1-12 weeks of age):						
Final body weight (g/bird)	2,035.83^{c}	2,295.17^{b}	2,347.50^{b}	2,472.00^{a}	4.83	<0.0001
Body weight gain (g/bird)	1,988.39^{c}	2,247.28^{b}	2,299.98^{b}	2,424.29^{a}	4.82	<0.0001
Cumulative feed intake (g/bird)	5,236.65^{b}	5,613.94^{a}	5,630.33^{a}	5,669.78^{a}	8.19	0.0003
Feed conversion ratio	2.635^{a}	2.498^{b}	2.449^{b}	2.339^{c}	0.005	0.0002
Survival rate (%)	99.38	99.67	99.67	100.00	0.04	0.4345

T1: control diet + 0% sardine head by-product powder, T2: control + 0.5% sardine head by-product powder, T3: control + 1.0% sardine head by-product powder, T4: control + 1.5% sardine head by-product powder; ^{a,b,c}Means within rows not sharing superscript are significantly different ($P<0.05$); SEM: Standard error of the mean

During the starter period, based on the data provided regarding the effects of sardine head by-products on Thai native chickens, the economic analysis of the starter period (1–4 weeks of age) reveals a clear inverse relationship between the inclusion of the fish by-products and production expenditures. As the concentration of sardine head by-product powder increased from 0% in the control group (T1) to 1.5% in the T4 group, the feed cost per kilogram progressively declined from 13.52 baht to 13.30 baht. This reduction in dietary cost, coupled with improved feed efficiency, where the feed-to-body weight gain ratio dropped from 2.22 in T1 to 2.12 in T4, resulted in a significant decrease in overall production costs. Specifically, the production cost per kilogram of gain was reduced by 2.56, 2.25, and 1.82 baht for the T2, T3, and T4 experimental groups, respectively, compared to the control.

In the grower period (5–8 weeks of age), the inclusion of sardine head by-product powder significantly enhanced the economic efficiency of Thai native chicken production by reducing overall costs as the concentration of the by-product increased. While the control group (T1) recorded a production cost of

38.34 baht/kg, the experimental groups T2 (0.5% inclusion), T3 (1.0% inclusion), and T4 (1.5% inclusion) achieved lower production costs of 35.11 baht/kg, 34.88 baht/kg, and 33.45 baht/kg, respectively. This resulted in a cost reduction ranging from 3.23 baht/kg to 4.89 baht/kg compared to the control diet, driven by both a lower feed cost per kilogram and a superior feed conversion ratio. These findings, based on local ingredient prices in Narathiwat province, suggest that utilising sardine head by-products as a 1.5% dietary supplement (T4) provides the most substantial financial benefit during the grower phase.

In the finisher period (9–12 weeks of age), the study observed a significant reduction in production costs associated with the inclusion of sardine head by-product powder in the diets of Thai native chickens. The control group (T1) exhibited the highest production cost at 40.81 baht/kg. In contrast, experimental groups T2 (0.5% inclusion), T3 (1.0% inclusion), and T4 (1.5% inclusion) showed progressively lower production costs of 37.16 baht/kg, 35.55 baht/kg, and 32.59 baht/kg, respectively. This resulted in substantial savings ranging from 3.65 baht/kg to 8.22 baht/kg compared to the control group. These financial improvements were driven by both reduced feed costs per kilogram and significantly improved feed efficiency, with the feed/body weight gain ratio decreasing from 3.27 in the control to 2.63 in the T4 group. These results indicate that a 1.5% inclusion rate of sardine head by-products provides the most optimal economic performance during the final growth stage.

In the total production period (1–12 weeks of age), incorporating sardine head by-product powder into the diets of Thai native chickens resulted in a clear reduction in production costs as the inclusion level increased. The control group (T1) recorded the highest total production cost at 34.64 baht/kg. In comparison, experimental groups T2 (0.5% inclusion), T3 (1.0% inclusion), and T4 (1.5% inclusion) achieved significantly lower costs of 32.15 baht/kg, 31.48 baht/kg, and 29.95 baht/kg, respectively. This reduction in cost, ranging from 2.49 to 4.69 baht/kg, was primarily driven by a more efficient feed/body weight gain ratio, which improved from 2.64 in the control to 2.34 in the T4 group, as well as a decrease in the overall feed cost per kilogram. These results, based on local ingredient prices in Narathiwat province, indicate that a 1.5% inclusion of sardine head by-products offers the most significant economic advantage for the entire 12-week rearing period, as shown in Table 5.

Table 5. Effects of sardine head by-products from fish cracker (keropok) processing on the feed costs of Thai native chickens

Feed-cost calculation	Experimental groups			
	T1	T2	T3	T4
Starter period (1-4 weeks of age):				
Feed/body weight gain	2.22	2.05	2.08	2.12
Feed cost (baht/kilogram)[1]	13.52	13.39	13.35	13.30
Production cost (baht/kilogram)	30.01	27.45	27.76	28.19
Grower period (5-8 weeks of age):				
Feed/body weight gain	2.87	2.73	2.73	2.63
Feed cost (baht/kilogram)[1]	13.36	12.86	12.78	12.72
Production cost (baht/kilogram)	38.34	35.11	34.88	33.45
Finisher period (9-12 weeks of age):				
Feed/body weight gain	3.27	2.98	2.86	2.63
Feed cost (baht/kilogram)[1]	12.48	12.47	12.43	12.39
Production cost (baht/kilogram)	40.81	37.16	35.55	32.59
Total period (1-12 weeks of age):				
Feed/body weight gain	2.64	2.49	2.45	2.34
Feed cost (baht/kilogram)[1]	13.12	12.91	12.85	12.80
Production cost (baht/kilogram)	34.64	32.15	31.48	29.95

T1: control diet + 0% sardine head by-product powder, T2: control + 0.5% sardine head by-product powder, T3: control + 1.0% sardine head by-product powder, T4: control + 1.5% sardine head by-product powder

[1]The prices of the experimental diets were based on the average costs of feed ingredients obtained from local feed supply stores in Mueang district, Narathiwat province, Thailand, during the period from October to December 2025.

Discussion

Productive performance

Our findings in the current study indicated that incorporating sardine head by-products (residue from keropok production) into the diet can enhance the productive performance of Thai native crossbred chickens. The observed favourable outcomes are likely attributable to the nutritionally rich composition of the sardine head by-products, which contains several crucial substances. These include essential fatty acids along with a significant content level of protein and various vitamins. Collectively, these valuable components are postulated to offer multiple benefits, promoting the overall health status and increasing the productive performance of native chicken breeds. According to Al-Marzooqi *et al*. (2010), sardine head by-products from keropok production have been identified as a nutritionally valuable source for use as a high-quality protein supplement in poultry feed. This finding is supported by Rashid *et al*. (2024), who reported that sardine head by-products from keropok production facilities

retain several crucial nutrients, including high-quality fat and protein, alongside a range of essential amino acids such as threonine (0.03%), lysine (0.11%), methionine (0.01%), valine (1.01%), isoleucine (0.11%), leucine (0.22%), and phenylalanine (0.05%), as well as various non-essential amino acids, specifically arginine (0.26%), glycine (0.14%), aspartic acid (0.52%), glutamic acid (0.38%), alanine (0.26%), proline (0.04%), and tyrosine (0.03%). Moreover, Bouriga *et al.* (2022) found that sardines are composed of several significant nutrients, particularly fatty acids, which include saturated fatty acids, monounsaturated fatty acids, and a high proportion of polyunsaturated fatty acids (PUFAs). This is consistent with Mkadem and Kaanane (2019), who found that fish by-products generated from sardine processing contain a relatively high oil content, with PUFAs ranging from 35.29% to 42.93%. Crucially, this lipid fraction includes the essential omega-3 fatty acids: eicosapentaenoic acid (EPA, 20:5 n-3), at 20.46–24.95%, and docosahexaenoic acid (DHA, 22:6 n-3), at 4.57–10.18%. The presence of high levels of EPA and DHA, several amino acids, proteins and vitamins contained in sardine head by-products from keropok production, is beneficial for enhancing the productive performance of Thai native crossbred chickens. Aidos (2002) also reported that fish oil is a highly recommended dietary supplement, primarily due to its abundance of polyunsaturated fatty acids (PUFAs). These bioactive compounds include eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), both of which are characterised by multiple omega-3 double bonds. Their presence renders fish oil beneficial for sustaining health and potentially enhancing the productive performance of native chickens.

These findings concur with prior research by Adugna *et al*. (2020), who demonstrated that using fish waste at a 5% inclusion level resulted in a significantly higher body weight gain and increased feed intake ($P>0.05$) compared to a control group. This is supported by Zainudin *et al*. (2025), who reported that supplementing native chicken diets with 5% skipjack tuna by-products led to increased final body weight and carcass weight, alongside a significantly improved feed conversion ratio (FCR) ($P<0.01$). The utilisation of these processing wastes, such as those from skipjack tuna, represents a sustainable strategy for poultry production, optimising resource use and enhancing the productive performance of native chickens. Furthermore, fish waste by-products are a valuable source of oil, providing energy and crucial long-chain n-3 unsaturated fatty acids, which have been shown to significantly improve the growth performance of broiler chickens by increasing body weight, improving FCR, and promoting overall health (Alparslan and Ozdogan, 2006; Farhoomand and Checaniazer, 2009; Pumchasov and Nir, 1992). These results are consistent with a previous study by Leke *et al*. (2018), which explored the use of fish oil, a by-product of the fish canning industry, in the diets of native

chickens and concluded that its inclusion improved their productive performance. Specifically, the study reported that incorporating fish oil into the diets at levels of up to 3% resulted in significant increases ($P<0.05$) in the production and carcass parameters including feed intake, body weight gain, carcass percentage, liver weight, breast weight, and thigh weight. According to Iriyanti *et al.* (2014), feeding native chickens a high-quality feed can boost their productivity. This could lead to improvements in their body weight. Sahena *et al*. (2009) confirmed that fish oil, especially when derived from fish waste, can be a beneficial energy source in poultry diets. Long-chain polyunsaturated fatty acids (PUFAs), specifically eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), are critical mediators of systemic health. Their biochemical utility in modulating inflammatory pathways and lipid profiles makes them essential in the prophylactic and therapeutic management of diverse chronic pathologies, including cardiovascular and neurodegenerative diseases. Furthermore, Leke *et al.* (2013) demonstrated the potential of utilising skipjack tuna industrial waste (specifically heads, entrails, and bones/carcasses) as a component in native hen feed formulations. Their findings indicated that including this waste product at a level of up to 15% in the ration was effective for optimising the birds' productivity. Another researcher confirmed that long-chain omega-3 polyunsaturated fatty acids (LC-n-3 PUFA), primarily derived from dietary sources such as fish oil and fishmeal, is well-documented to confer significant benefits to increase meat quality and promote the growth performance of broiler chickens. Specifically, the presence of these lipids, including eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3), has been shown to enhance growth performance and positively influence meat consistency in broiler chickens by increasing the concentration of these essential fatty acids within the muscle tissue (Pumchasov and Nir, 1992). Beyond performance metrics, the delivery of these LC-n-3 PUFAs via fish lipids is broadly recognised for promoting various health-related improvements in both human and animal subjects, underscoring the functional and nutritional value of incorporating these sources into animal diets (Crespo and Esteve-Garcia, 2001). Additionally, Leke *et al.* (2018) found that fish oil, a by-product of the fish canning industry, is rich in fatty acid content, specifically containing docosahexaenoic acid (DHA) at 601 mg/100g, eicosapentaenoic acid (EPA) at 84 mg/100g, and a total omega-3 fatty acid concentration of 0.69%. Increasing fish oil levels significantly elevated both the total omega-3 polyunsaturated fatty acid (PUFA) and monounsaturated fatty acid (MUFA) content of the formulated feed. This enhanced fatty acid profile is the likely basis for the observed positive effects on poultry performance and carcass quality. Moreover, Liu *et al*. (2014) claimed that fish oil, rich in omega-3 polyunsaturated fatty acids, was demonstrated to modify abdominal fat

deposition and improve circulating lipid profiles in broilers. Furthermore, fish oil exerted an anti-inflammatory effect by inhibiting phospholipase A_2 production in broiler chickens, consequently reducing proinflammatory eicosanoid content. Therefore, utilising fish by-products and processing waste offers a significant opportunity for sustainable and environmentally friendly poultry production, contributing to the overall development of sustainable animal agriculture (Ramírez *et al*., 2016).

Feed production costs

The findings showed that the integration of sardine head by-products into the diets of Thai native chickens represents a significant advance in sustainable poultry production and cost-efficiency. According to the study, the inclusion of sardine head by-products at a 1.5% rate (T4) consistently reduced production costs across all growth stages, culminating in a total cost reduction of 4.69 baht/kg over the 12-week period. This economic improvement is primarily attributed to the dual benefit of lower feed costs per kilogram and an enhanced feed conversion ratio (FCR). In the context of global poultry production, feed typically accounts for 65–70% of total operating expenses (Adugna *et al*., 2020). By substituting expensive protein concentrates with fishery waste, producers can mitigate the financial volatility of conventional feed ingredients like soybean meal and corn. The utilisation of sardine head by-products aligns with the principles of the circular economy, which advocates for the upcycling of agro-industrial waste into high-value animal protein. As noted by Rashid *et al*. (2024), sardine fish by-products are rich in essential amino acids and minerals, which likely contributed to the improved biological efficiency observed in the T4 group, where the total FCR improved from 2.64 to 2.34.

For growth stage dynamics and feed conversion optimisation, the study reveals that the economic impact of sardine head by-product inclusion becomes more pronounced as the chickens mature, with the most substantial savings occurring during the finisher period (9–12 weeks). During this stage, the production cost in the T4 group was 8.22 baht/kg lower than the control, a marked improvement compared to the 1.82 baht/kg saving in the starter phase. This trend is academically significant because feed intake increases exponentially as birds reach physiological maturity. Consequently, any improvement in feed efficiency or reduction in unit cost during the finisher phase has a disproportionately large impact on total profitability. The observed decrease in FCR from 3.27 (T1) to 2.63 (T4) during the final weeks suggests that sardine head by-products provide a highly bioavailable nutrient profile that meets the increased maintenance and growth requirements of native chickens. Previous

research has indicated that beneficial compounds produced from fish, including proteins, lipids, enzymes, pigments, and vitamins, can enhance the metabolic efficiency of indigenous breeds, which is often characterised by slower growth rates but higher resilience than commercial broilers. The ability of sardine head by-products to optimise the FCR during the high-intake finisher period is a critical factor in maximising the return on investment for smallholder farmers. Thus, converting these wastes into marketable products is critical for increasing value while reducing environmental pollution. Using non-traditional, locally available feed components, poultry farms can generate cost-effective feed formulas that help reduce feed costs (Abasubong *et al*., 2025).

The findings are particularly relevant to the socio-economic landscape of Narathiwat province, where the availability of sardine by-products from fish cracker processing provides a localised, low-cost raw material. Utilising local ingredients reduces the food miles associated with feed logistics and supports the local fishery industry by creating a market for what would otherwise be environmental waste. From an academic standpoint, the localisation of feed resources is a key strategy for enhancing the resilience of rural poultry systems (Prakash *et al*., 2013). The reduction in production cost from 34.64 baht/kg to 29.95 baht/kg (T4) directly translates to increased net margins for Thai native chicken farmers. Native chickens often command a premium price in local markets due to their meat texture and flavour; therefore, reducing the cost of production without compromising growth performance, as demonstrated by the improved FCR, creates a highly competitive advantage. This study confirms that 1.5% inclusion is not only biologically viable but also the most economically optimal level within the specific market conditions of Southern Thailand. The success of the T4 diet (1.5% sardine head by-products) suggests a nutritional synergy between the fish by-product and the basal diet components. Fish heads are known to be concentrated sources of calcium, phosphorus, and omega-3 fatty acids, which may have contributed to better skeletal development and metabolic health, indirectly leading to the lower production costs through reduced wastage and better nutrient absorption (Noreen *et al*., 2025). Furthermore, the steady decline in feed cost per kilogram (from 13.52 to 13.30 baht in the starter phase) indicates that sardine head by-products are a cost-effective alternative to conventional additives. As the poultry industry faces increasing pressure to find sustainable alternatives to fishmeal, which is often criticised for its environmental impact on marine stocks, using by-products rather than whole fish offers a more ethical and sustainable pathway. This study contributes to the growing body of evidence that "waste-to-feed" strategies are essential for the future of poultry science, providing a model that balances biological performance with economic pragmatism.

The findings are allowed the conclusion that the inclusion of sardine head by-products significantly enhanced body weight gain and feed efficiency in Thai native chickens across all growth phases. Optimal results were observed at the 1.5% inclusion level (T4), which yielded a superior final body weight of 2,472 g and a minimum feed conversion ratio (FCR) of 2.339, while ensuring a 100% survival rate during the latter half of the trial. These results suggest that this by-product is both a safe and effective alternative protein source for optimising poultry productivity. Furthermore, substituting standard feed with up to 1.5% sardine head by-products proved highly economical, improving feed efficiency and reducing total production costs by 4.69 baht/kg over the 12-week experimental period. Further studies are recommended to assess the long-term physiological effects of incorporating sardine head by-products into poultry diets, including impacts on immune function, gut microbiota balance, metabolism, and health. Moreover, comprehensive assessments of carcass traits and meat quality parameters should be considered.

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Conflicts of interest

The authors confirm that they have no conflicts of interest – financial or otherwise – to disclose that could be construed as influencing the results or interpretations of this paper.

References

Abasubong, K. P., Amin, A. B., Uwem, G. U. and Desouky, H. E. (2025). A review of fish waste and byproducts in poultry production: effects on growth, egg quality, carcass traits, and broader knowledge beyond physiological response. Animal Advances, 2:1-14. https://doi.org/10.48130/animadv-0025-0027.

Adugna, A. A., Habib, K. M., Odier, O. and Gebresilase, T. (2020). Effects of fish by-product meal inclusion in broiler feeds on growth performance. Journal of Experimental Agriculture International, 42:76-81. https://doi.org/10.9734/jeai/2020/v42i730556.

Aidos, I., Jacobsen, C., Jensen, B., Luten, J. B., van der Padt, A. and Boom, R. M. (2002). Volatile oxidation products formed in crude herring oil under accelerated oxidative conditions. European journal of lipid science and technology, 104:808-818. https://doi.org/10.1002/1438-9312(200212)104:12%3C808::AID EJLT808%3E3.0.CO;2-J

Al-Marzooqi, W., Al-Farsi, M. A., Kadim, I., Mahgoub, O. and Goddard, J. S. (2010). The effect of feeding different levels of sardine fish silage on broiler performance, meat quality and sensory characteristics under closed and open-sided housing systems. Asian-Australasian Journal of Animal Sciences, 9:932-937. https://doi.org/10.5713/ajas.2010.10119.

Alparslan, G. and Özdogan, M. (2006). The effects of diet containing fish oil on some blood parameters and the performance values of broilers and cost efficiency. International Journal of Poultry Science, 5:415-419. https://doi.org/10.3923/ijps.2006.415.419.

Bai, A., Ruban, S. W., Spandan P. V., Barry, A. I. G., Kumar, S. N., Indresh, H. C. and Nagaraja, C. S. (2022). Carcass and meat quality characteristics of native chicken reared under backyard and farm setting in Karnataka. Asian Journal of Dairy and Food Research, 41:111-115. doi: 10.18805/ajdfr.DR-1699.

Bouriga, N., Bahri, W. R., Mili, S., Massoudi, S., Quignard, J. and Trabelsi, M. (2022). Variations in nutritional quality and fatty acids composition of sardine (*Sardina pilchardus*) during canning process in grape seed and olive oils. Journal of Food Science and Technology, 59:4844-4852. https://doi.org/10.1007/s13197-022-05572-4.

Chomchuen, K., Tuntiyasawasdikul, V., Chankitisakul, V. and Boonkum, W. (2022). Genetic evaluation of body weights and egg production traits using a multi-trait animal model and selection index in Thai native synthetic chickens (Kaimook e-san2). Animals, 12:335. https://doi.org/10.3390/ani12030335.

Crespo, N. and Esteve-Garcia, E. (2001). Dietary fatty acid profile modifies abdominal fat deposition in broiler chickens. Poultry Science, 80:71-78. https://doi.org/10.1093/ps/80.1.71.

Dudung A. M. (1990). Memelihara ayam kampung sistem battery. Kanisius, Yogyakarta, pp.1-13.

Farhoomand P. and Checaniazer S. (2009). Effects of graded levels of dietary fish oil on the yield and fatty acid composition of breast meat in broiler chickens. Journal of Applied Poultry Research, 18:508-513. Doi:10.3382/japr.2008-00137.

Ideia, P., Pinto, J., Ferreira, R., Figueiredo, L., Spínola, V., Castilho and Paula C. (2020). Fish processing industry residues: A review of valuable products extraction and characterization methods. Waste and Biomass Valorization, 11:3223-3246. https://doi.org/10.1007/s12649-019-00739-1.

Iriyanti, N., Santosa, R.S.S. and Rachmawati. (2014). Blood profile and performance of native chicken with functional feed. International Journal of Poultry Science, 13:645-651.

Jaturasitha, S., Srikanchai, T., Kreuzer, M. and Wicke, M. (2008). Differences in carcass and meat characteristics between chicken indigenous to northern Thailand (black-boned and Thai native) and imported extensive breeds (bresse and Rhode Island Red). Poultry Science, 87:160-169. Doi:10.3382/ps.2006-00398.

Kridtayopas, C., Danvilai, W., Sopannarath, P., Kayan, A. and Loonyai, W. (2019). A study of growth performance, carcass characteristic, meat quality and association of polymorphisim in the Apo VLDL-II gene with fat accumulation in the female broiler, Thai native and Betong chickens (KU line). International Journal of Animal and Veterinary Sciences, 13:167-170.

Kris-Etherton, P. M. and Harris W. S. (2002). Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease. Circulation, 106:2747-2757. Doi: 10.1161/01.cir.0000038493.65177.94.

Leke, J. R., Sjofan, A. O. and Najoan, M. (2013). Egg internal quality and n-3 fatty acids of native chicken fed on Skipjack fish (*Katsuwonus pelamis*. I) industrial waste containing feed. International Journal of Poultry Science, 12:484-488. https://doi.org/10.3923/ijps.2013.484.488

Leke, J. R., Mandey, J. S., Laihad, J. T., Tinangon, R. M., Tangkau, L. and Junus, C. (2018). Performance and lipid profiles of native chickens fed diet containing Skipjack fish oil as by-product of fish canning factory. IOP Conference Series: Earth and Environmental Science, 102:012041. DOI: 10.1088/1755-1315/102/1/012041.

Liu, G., An, S., Yuan, J., Guo, Y., Liu, D., Chen, H. and Huang, R. (2014). Dietary fish oil and zinc reduced plasma prostaglandin E2 content by inhibiting phospholipase A2 Production in Broilers. Japan Poultry Science Association, 51:66-70. Doi:10.2141/ jpsa.0130059.

Mkadem, H. and Kaanane, A. (2019). Recovery and characterization of fish oil from by-products of Sardine (*Sardina pilchardus*) in the canning process. Journal of Aquatic Food Product Technology, 28:1037-1050.

Noreen, S., Hashmi, B., Aja, P. M. and Atoki, A. V. (2025). Health benefits of fish and fish by-products—a nutritional and functional perspective. Frontiers Nutrition, 12:1-13. Doi: 10.3389/fnut.2025.1564315.

Prakash, V., Ambuko, J., Belik, W., Huang, J. and Timmermans, T. (2013). Food losses and waste in the context of sustainable food systems V0 draft. Committee on World Food Security. Food and Agriculture Organization, 1-82.

Ralahalu, T. N., Latupeirissa, C. H. C. E., Hehanussa, S. C. H. H. and Fredriksz, S. (2021). Performance of native chicken fed on ration containing fermented sago waste. International Seminar on Agriculture, Biodiversity, Food Security and Health. IOP Conference Series: Earth and Environmental Science, 883. Doi:10.1088/1755-1315/883/1/012084.

Ramírez, J. C. R., Espain, J. I. I., Leyva, R. G., Ulloa, J. A. and Ulloa, P. R. (2016). Use of biological fish silage in broilers feed: Effect on growth performance and meat quality. Journal of Animal and Plant Sciences, 27:4293-4304. https://doi.org/10.35759/JAnmPlSci.v27-3.4.

Rashid, N. Y. A., Indran, S. R., Manan, M. A., Pa'ee, K. F., Saari, N. and Wong, F. W. F. (2024). Valorization of Malaysian Fish Sausage (Keropok Lekor) By-Products into Bioactive

Fish Protein Hydrolysate by Bacillus licheniformis Fermentation: Influence of By-Products Characteristics on Nutritional, Antioxidant and Antibacterial Capacities. Waste and biomass valorization, 15:3169-3185. https://doi.org/10.21203/rs.3.rs-3319160/v1.

Ruxton, C. (2007). The health benefits of omega-3 polyunsaturated fatty acids: A review of the evidence. Journal of Human Nutrition and Dietetics, 17:449-459.

Sahena, F., Zaidul, I. S. M., Jinap, S., Saari, N., Jahurul, H. A., Abbas, K. A., and Norulaini, N. A. (2009). PUFAs in fish: extraction, fractionation, importance in health. Comprehensive Reviews in Food Science and Food Safety, 8:59-74. https://doi.org/10.1111/j.1541-4337.2009.00069.x.

SAS Institute Inc. (2017). *SAS/STAT® 14.3 user's guide*. SAS Institute Inc.

Tunim, S., Phasuk, Y., Aggrey. S. E. and Duangjinda, M. (2021). Gene expression of fatty acid binding protein genes and its relationship with fat deposition of Thai native crossbreed chickens. Animal Bioscience, 34:751-758. https://doi.org/10.5713/ajas.20.0020.

Wattanachant, S., Benjakul, S. and Ledward, D. (2004). Composition, color and texture of Thai indigenous and broiler chicken muscles. Poultry Science, 83:123-128. https://doi.org/10.1093/ps/83.1.123.

Zainudin, S., Hartutik, Sudjarwo, E. and Sjofjan, O. (2025). The Effects of Replacing Fish Meal with Skipjack Tuna Offal Meal on the Growth Performance and Carcase Quality of Local Chickens. Advances in Animal and Veterinary Sciences, 13:2309-3331. https://dx.doi.org/10.17582/journal.aavs/2025/13.1.43.50.

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