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Partial or Complete Replacement of Yellow Corn with Biscuit By-Product in Diets for the Nile Tilapia (*Oreochromis niloticus*) Fingerlings

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ABSTRACT

This study evaluated the effects of partially or fully replacing yellow corn with biscuit by-product (BBP) at inclusion levels of 0, 10, 20, and 30% on the growth performance, feed utilization, body composition, blood parameters, energy retention (ER%), protein productive value (PPV%), and economic efficiency of the Nile tilapia (*Oreochromis niloticus*). A total of 120 fingerlings (181 ± 0.33 g) were randomly assigned to 12 aquaria (100 L capacity), each stocked with 10 fish. Proximate analysis of BBP revealed 96.82% dry matter (DM), 10.22% crude protein (CP), 2.56% crude fiber (CF), 8.83% ether extract (EE), 69.27% nitrogen-free extract (NFE), 9.12% ash, and 4,388 kcal/kg DM gross energy. All experimental diets were formulated to be iso-nitrogenous and iso-caloric (29.58–29.90% CP and 4,554–4,562 kcal/kg DM gross energy). Growth parameters—including final weight, total gain, average daily gain (ADG), and specific growth rate (SGR)—were significantly ($P< 0.05$) improved in BBP-fed groups, with 100% survival observed in D2, D3, and D4. In addition, feed conversion ratio (FCR) and protein efficiency ratio (PER) improved significantly. Most blood parameters were significantly affected, except for globulin, the albumin-to-globulin ratio, creatinine, and bilirubin. Body composition analysis showed significant increases in DM, CP, and ash, alongside reductions in moisture, organic matter (OM), EE, and gross energy ($P< 0.05$). ER% improved by 16.94, 33.95, and 45.14%, and PPV% by 51.07, 53.09, and 54.46% in D2–D4, respectively, compared to the control. Economically, BBP inclusion reduced feed costs while improving returns, with no adverse effects on growth or health. These findings indicate that BBP can serve as a cost-effective and nutritionally viable alternative to corn in tilapia diets.

INTRODUCTION

Biscuit, derived from the Latin term *biscoctum*—meaning “twice-cooked bread”—is a widely consumed and affordable processed food enjoyed by all age groups.

In European countries, it is known as “biscuits,” while in the Americas, it is referred to as “cookies.” Their popularity stems from their appealing taste, long shelf life, wide availability, and low production cost **(Vitali *et al.*, 2009)**. Biscuits are typically composed of flour, fat, sugar, water, milk, and salt, with optional additives to enhance taste, nutritional quality, or shelf stability **(Morais *et al.*, 2018)**. Their extended shelf life enables large-scale production and efficient distribution, making them suitable for both domestic and international markets.

Historically, biscuit-like products have been consumed for centuries and are recognized as convenient, nutrient-dense snacks that can be fortified to meet specific dietary needs **(Awobusuyi *et al.*, 2020)**. Their origins can be traced back nearly 10,000 years, when early civilizations discovered that heat-treated cereal dough yielded durable, transportable food ideal for long journeys **(Galleta, 2023)**.

Nutritionally, biscuits are rich in carbohydrates, saturated fats, and calories but generally lack sufficient protein, fiber, vitamins, and minerals **(Farzana *et al.*, 2022)**. Wheat flour, the primary ingredient, contains 7–14% protein but is typically low in essential amino acids such as lysine **(Baljeet *et al.*, 2010)**. Excessive biscuit consumption, particularly among children, has been linked to weight gain; for example, each additional megajoule from biscuits or similar foods increases the risk of overweight by 24% in children aged 7–18 **(Gibson *et al.*, 2004)**. Addressing this issue requires a holistic approach involving both dietary management and physical activity.

Corn grain is a major energy source in animal feed, often comprising 40–60% of total diet content. However, its high cost has driven the search for cost-effective alternatives **(Payne, 2005)**. Biscuit waste, a food industry by-product, offers a comparable nutritional profile to corn in terms of protein and energy content, and has been successfully incorporated into poultry diets, reducing feed costs without negatively affecting performance.

Tilapia (*Oreochromis niloticus*) is a versatile species capable of utilizing diverse feed ingredients, including agricultural by-products and food industry residues **(Galindo *et al.*, 2009)**. Rising prices of conventional feed ingredients have prompted nutritionists to explore alternative components with comparable or superior nutrient profiles. However, the success of such substitutions depends on understanding the digestibility, energy contribution, and specific nutrient composition of these alternatives, as well as the nutritional requirements of the species **(Boscolo *et al.*, 2002; Pezzato *et al.*, 2002)**.

Wheat-based by-products from biscuit and noodle production have nutritional profiles closely resembling energy grains, making them potential replacements for maize **(Gignor *et al.*, 2007; Boscolo *et al.*, 2010; Rostagno *et al.*, 2011)**. Additionally, incorporating biscuit waste into the diets of livestock such as snails and rams has proven to be cost-effective and performance-neutral, suggesting broader applicability in animal farming **(Apata *et al.*, 2010; Adeyemo *et al.*, 2013)**.

In this context, the present study was designed to evaluate the effects of partially or fully replacing yellow corn with biscuit by-product on growth performance, feed efficiency, body composition, hematological parameters, energy retention, protein productive value, and economic viability in the Nile tilapia (*Oreochromis niloticus*).

MATERIALS AND METHODS

This study was conducted at the Fish Laboratory of the Fish Nutrition and Feed Technology Department, Central Laboratory for Aquaculture Research (CLAR), Agricultural Research Center, Abbassa, Abu-Hammad 44661, Sharkia, Egypt, in collaboration with the Animal Production Department, Biological Agriculture Research Institute, National Research Center. The objective was to evaluate the effects of partially or fully replacing yellow corn—constituting 30% of the control diet (D1)—with biscuit by-product (BBP) at three inclusion levels: 10% (D2), 20% (D3), and 30% (D4). The study assessed growth performance, feed utilization, body composition, hematological parameters, energy retention (ER%), protein productive value (PPV%), and the economic efficiency of the Nile tilapia (*Oreochromis niloticus*).

Experimental unit

A total of 120 *O. niloticus* fingerlings, with an initial average body weight of 181 ± 0.33 g, were used. Following an acclimatization period, fish were randomly assigned to four dietary treatments, each with three replicates. Ten fish were stocked per replicate in 12 glass aquaria, each with a capacity of 100 L.

Experimental diets

The formulation of the experimental diets and the chemical composition of the tested diets are presented in Table (1).

Table 1. Composition of the different experimental diet’s ingredients

Item	Experimental diets				
	Zero % BBP	**10% BBP**	**20% BBP**	**30% BBP**	**Price of tone LE**
	D1	**D2**	**D3**	**D4**	
Yellow corn	**30.00**	**20.00**	**10.00**	**00.00**	**12500**
Biscuits by-product (BBP)	**00.00**	**10.00**	**20.00**	**30.00**	**7000**
Wheat bran	**20.00**	**20.00**	**20.00**	**20.00**	**14500**
Protein concentration	**24.00**	**24.00**	**24.00**	**24.00**	**25000**
Soybean meal (SBM)	**24.00**	**24.00**	**24.00**	**24.00**	**33000**
Vegetable oil	**1.00**	**1.00**	**1.00**	**1.00**	**50000**
Salt (sodium chloride)	**0.50**	**0.50**	**0.50**	**0.50**	**5000**
Vitamin and Minerals*	**0.50**	**0.50**	**0.50**	**0.50**	**40000**
Price of ton fed (LE)	**21295**	**20745**	**20195**	**19645**	**---**
Price of kg fed (LE)	**21.295**	**20.745**	**20.195**	**19.645**	**---**

Biscuits by-product (BBP)
** Vit. A (E672) (IU) 876.19, Vit. D3 (IU) 1141.39, Vit. E 114.30, Vit. K3 7.55, Vit. B1 13.71, Vit. B2 11.44, Vit. B6 15.33, Vit. B12 0.03, Niacin 60.96, Calpan 30.48, Folic Acid 3.04, Biotin 0.37, Vit. C 11.44, Selenium 0.27, Manganese 19.04, Iron 9.15, Iodine 0.77, Zinc 76.19, Copper 3.04, Cobalt 0.37, Choline Chloride 457.14, and Antioxidant 95.23 (Vit. vitamin; IU international unit).
Price of tone LE According to 2023.

All Nile tilapia were fed the experimental diets twice daily at 8:00 a.m. and 4:00 p.m., at a feeding rate of 3% of their live body weight. The feeding trial lasted for 70 days, approximately from mid-November 2023 to the end of January 2024.

Parameters of growth performance

Body weight gain (BWG) = Final weight - Initial weight.

Survival rate (SR %) = Number of fish at final / Number of fish at start x100.

Specific growth rate (SGR) =

[In final weight (g) - In initial weight (g)] / Experimental days *100

Calculation of feed conversion ratio (FCR)

FCR = total dry matter intake, (TDMI), g / total body weight gain (TBWG), g.

Calculation of crude protein efficiency ratio (CPER)

(PER) = total body weight gain (TBWG), g / total crude protein intake (TCPI), g.

Feed efficiency (FE %) = [weight gain (g) / feed intake (g)]

Mortality rate% = Number of fish dead at end of the experiment * 100 / Number of fish at the beginning of the experiment.

Protein productive value (PPV %) = [PR_1– PR_0 / PI] * 100.

Where: PR_1 = is the total fish body protein at the end of the experiment.

PR_0 = is the total fish body protein at the start of the experiment.

PI = Protein intake.

Energy retention percentages (ER %)

The energy retention percentage (ER%) was calculated to determine the proportion of dietary energy retained in the fish body over the experimental period. The following equation was used:

ER (%) = [(E − E_0) / EF] × 100

Where:

E = Energy content of the fish carcass (kcal) at the end of the experiment

E_0 = Energy content of the fish carcass (kcal) at the beginning of the experiment

EF = Total energy intake from feed (kcal)

This calculation provides insight into how effectively the consumed energy was converted into body energy.

Blood sampling

Blood samples were collected from the caudal vein of 16 fish using a 3mL syringe after anesthetizing the fish with clove oil at a concentration of 0.5mL L^{-1}. The samples were placed in clean, dry centrifuge tubes and left at room temperature to clot. After clotting, the samples were centrifuged at 3000 rpm for 15 minutes. The resulting serum was carefully separated, collected, and stored at −20 °C until biochemical analysis.

Body composition

At the start of the experiment, 10 fish were stocked per aquarium. At the end, five fish from each treatment were randomly selected for whole-body composition analysis.

Analytical procedures

The proximate composition of the basal diet and fish body was analyzed according to **AOAC (2016)**.

Biochemical assays

Serum total protein was determined according to the methods of **Armstrong and Carr (1964)**, **Cannon *et al.* (1974)** and **Witt and Trendelenburg (1982)**. Albumin concentration was measured following the protocols of **Doumas *et al.* (1971)**, **Tietz (1986)** and **Tietz (1990)**. Globulin levels were calculated by subtracting albumin concentration from total protein concentration, and the albumin-to-globulin (A/G) ratio was obtained by dividing albumin by globulin. Alanine aminotransferase (ALT) and aspartate aminotransferase (AST) activities were measured according to **Reitman and Frankel (1957)** and **Harold (1975)**. Uric acid and creatinine levels were determined following **Tietz (1990)**. Total cholesterol was assessed according to **Allain *et al.* (1974)**, **Ellefson and Caraway (1976)** and **Pisani *et al.* (1995)**. All biochemical parameters were analyzed using commercial diagnostic kits (Spectrum Diagnostics, Egypt) and were measured colorimetrically with an Agilent Cary UV-Vis spectrophotometer (100/300 Series), following the manufacturer's instructions.

Calculated data

Gross energy (kcal/kg dry matter) of the experimental diets and fish body composition was calculated according to **Blaxter (1968)** and **MacRae and Lobley (2003)**, using caloric values of 5.65 kcal/g for crude protein (CP), 9.40 kcal/g for ether extract (EE), and 4.15 kcal/g for both crude fiber (CF) and nitrogen-free extract (NFE). Metabolizable energy (ME) was calculated based on the **NRC (2011)** recommendations, using conversion factors of 4.50 kcal/g for protein, 8.15 kcal/g for fat, and 3.49 kcal/g for carbohydrates. The protein-to-energy ratio (mg CP/kcal ME) was also determined according to the **NRC (2011)**.

Statistical analysis

Data were analyzed using one-way analysis of variance (ANOVA) in **SPSS (2020)**. Differences among treatment means were evaluated using Duncan's Multiple Range Test **(Duncan, 1955)**.

RESULTS

Chemical analysis of biscuits by-product (BBP)and the other feed ingredients

Results in Table (2) show that the biscuit by-product (BBP) contained 96.82% dry matter (DM), 10.22% crude protein (CP), 2.56% crude fiber (CF), 8.83% ether extract (EE), 69.27% nitrogen-free extract (NFE), 9.12% ash, 4,388 kcal/kg DM gross energy (GE), 359.71 kcal/kg DM metabolizable energy (ME), and a protein-to-energy ratio of 28.41 mg CP/kcal ME. Compared to yellow corn, BBP had higher DM, CP, CF, EE, and protein-to-energy ratio, while yellow corn contained higher levels of organic matter (OM), NFE, GE, and ME.

Table 2. Chemical analysis of biscuits by-product (BBP)and the other feed ingredients used in diets formulations

Item	Feed ingredients				
	BBP	YC	WB	SBM	PC
Dry matter (DM)	**96.82**	**90.23**	**90.04**	**90.50**	**96.95**
Chemical analysis on DM basis					
Organic matter (OM)	**90.88**	**98.34**	**94.64**	**93.39**	**93.22**
Crude protein (CP)	**10.22**	**9.15**	**13.66**	**44.00**	**56.43**
Crude fiber (CF)	**2.56**	**2.48**	**8.56**	**3.69**	**2.84**
Ether extract (EE)	**8.83**	**3.75**	**3.81**	**2.83**	1.55
Nitrogen free extract (NFE)	**69.27**	**82.96**	**68.61**	**42.87**	**32.50**
Ash	**9.12**	**1.66**	**5.36**	**6.61**	**6.68**
Gross energy kcal/ kg DM	**4388**	**4415**	**4332**	**4684**	**4801**
Gross energy cal/ g DM	**4.388**	**4.415**	**4.332**	**4.684**	**4.801**
Metabolizable energy kcal/ kg DM	**359.71**	**361.27**	**331.97**	**370.68**	**379.99**
Protein energy ratio (mg CP/ Kcal ME)	**28.41**	**25.33**	**41.15**	**118.70**	**148.50**

BBP: Biscuits by-product. YC: Yellow corn, SBM: Soy bean meal, WB: Wheat bran, PC: Protein concentration, Gross energy (kcal/ kg DM) was calculated according to **Blaxter (1968)** and **MacRae and Lobley (2003)**. Where, each g CP = 5.65 Kcal, g EE = 9.40 kcal and g CF and NFE = 4.15 Kcal, Metabolizable energy (ME): Calculated using values of 4.50, 8.15 and 3.49 Kcal for protein, fat and carbohydrate, respectively. Calculated according to **NRC (2011)**, Protein energy ratio (mg CP/ Kcal ME): Calculated according to **NRC (2011)**.

Data presented in Table (3) indicate that all experimental diets were formulated to be iso-caloric and iso-nitrogenous. The crude protein (CP) content ranged from 29.58% to 29.90% across the four tested diets. Gross energy (GE) values ranged from 4554 to 4562 kcal/kg DM, while metabolizable energy (ME) values ranged from 362.66 to 363.17 kcal/kg DM. Additionally, the protein-to-energy ratio varied between 81.45 and 82.45 mg CP/kcal ME. These values are considered adequate to meet the nutritional requirements of the Nile tilapia.

Table 3. Chemical analysis of different experimental diets

Item	Zero% BBP Control	Replace YC by BBP at different levels		
		10% BBP	20% BBP	30% BBP
	D_1	D_2	D_3	D_4
Dry matter (DM)	**91.05**	**91.71**	**92.36**	**93.03**
Chemical analysis on DM basis				
Organic matter (OM)	**94.26**	**93.52**	**92.77**	**92.02**
Crude protein (CP)	**29.58**	**29.68**	**29.79**	**29.90**
Crude fiber (CF)	**4.02**	**4.04**	**4.04**	**4.05**
Ether extract (EE)	**3.94**	**4.44**	**4.96**	**5.46**
Nitrogen free extract (NFE)	**56.72**	**55.36**	**53.98**	**52.61**
Ash	**5.74**	**6.48**	**7.23**	**7.98**
Gross energy kcal/ kg DM	**4562**	**4559**	**4557**	**4554**
Gross energy cal/ g DM	**4.562**	**4.559**	**4.557**	**4.554**
Metabolizable energy kcal/ kg DM	**363.17**	**362.95**	**362.87**	**362.66**
Protein energy ratio (mg CP/ Kcal ME)	**81.45**	**81.77**	**82.10**	**82.45**

BBP: Biscuits by-product. Y.C: Yellow corn. Gross energy (kcal/ kg DM) was calculated according to **Blaxter (1968)** and **MacRae and Lobley (2003)**. Where, each g CP = 5.65 Kcal, g EE = 9.40 kcal and g CF and NFE = 4.15 Kcal.Metabolizable energy (ME): Calculated using values of 4.50, 8.15 and 3.49 Kcal for protein, fat and carbohydrate, respectively. Calculated according to **NRC (2011)**. Protein energy ratio (mg CP/ Kcal ME): Calculated according to **NRC (2011)**.

Growth performance, specific growth, and survival ratio

Data in Table (4) indicate that final weight (FW), total body weight gain (TBWG), average daily gain (ADG), and specific growth rate (SGR) were significantly (P< 0.05) higher in fish fed diets where yellow corn (30% of the control diet) was partially or fully replaced with biscuit by-product (BBP) at 10, 20, and 30% inclusion levels (D2, D3, and D4, respectively). Survival rate (SR) in the control group (D1) was 93.33%, with a mortality rate of 6.67%, whereas all BBP-fed groups achieved 100% SR and 0% mortality. Overall, BBP inclusion produced a significant (P< 0.05) positive impact on growth performance parameters.

Table 4. Growth performance, specific growth rate and survival ratio of different experimental groups

Item	Zero% BBP Control	Replace YC by BBP at different levels			SEM	Sign. *P*<0.05
		10% BBP	20% BBP	30% BBP		
	D_1	D_2	D_3	D_4		
Number of fish	30	30	30	30	-	-
Initial weight, g (IW)	181	180	182	181	0.326	NS
Final weight, g (FW)	236^b	272^a	275^a	278^a	5.822	*
Total body weight gain, g (TBWG)	55^b	92^a	93^a	97^a	5.891	*
Duration experimental period	70 days					
Average daily gain, g (ADG)	0.79^b	1.31^a	1.33^a	1.39^a	0.084	*
Specific growth rate (SGR)	0.32^b	0.52^a	0.53^a	0.56^a	0.033	*
Number of fish at the starter	30	30	30	30	-	-
Number of fish at the end	28	30	30	30	-	-
Survival ratio (SR)	93.33	100	100	100	-	-
Number of dead fish	2	Zero	Zero	Zero	-	-
Mortality rate percentages	6.67	Zero	Zero	Zero	-	-

BBP: Biscuits by-product. Y.C: Yellow corn. a and b: Means in the same row having different superscripts differ significantly ($P<0.05$). SEM: Standard error of mean. NS: Not significant. *: Significant at ($P<0.05$).

Feed utilization of the different experimental groups

Data presented in Table (5) revealed that feed intake (FI), feed conversion ratio (FCR), crude protein intake (CPI), and protein efficiency ratio (PER) were significantly ($P< 0.05$) improved with increasing the levels of biscuit by-product (BBP) inclusion in the diets of the Nile tilapia.

Table 5. Feed utilization of the different experimental groups

Item	Zero% BBP Control	Replace YC by BBP at different levels			SEM	Sign. P<0.05
		10% BBP	20% BBP	30% BBP		
	D_1	D_2	D_3	D_4		
Total body weight gain, g (TBWG)	**55^{b}**	**92^{a}**	**93^{a}**	**97^{a}**	**5.891**	*
Feed intake (FI), g	**438^{b}**	**475^{a}**	**470^{a}**	**482^{a}**	**6.134**	*
Feed conversion ratio (FCR)	**7.96^{b}**	**5.16^{a}**	**5.05^{a}**	**4.97^{a}**	**0.486**	*
Feed crude protein %	**29.58**	**29.68**	**29.79**	**29.90**	-	-
Crude protein intake (CPI), g	**129.56^{b}**	**140.98^{a}**	**140.01^{a}**	**144.12^{a}**	**1.819**	*
Protein efficiency ratio (PER)	**0.425^{b}**	**0.653^{a}**	**0.664^{a}**	**0.673^{a}**	**0.036**	*

BBP: Biscuits by-product. Yellow corn. a and b: Means in the same row having different superscripts differ significantly (P<0.05). SEM: Standard error of mean, NS: Not significant, *: Significant at (P<0.05).

Blood parameters of the different experimental groups

Results of all blood parameters presented in Table (6) indicate that the inclusion of biscuit by-product (BBP) in the fish diets had a significant ($P<0.05$) effect on most blood parameters, except for globulin, albumin/globulin (A/G) ratio, creatinine, and bilirubin, which were not significantly affected ($P>0.05$). Fish fed the diet containing 30% BBP (D4) showed the highest levels of total protein, albumin, globulin, glucose, AST, ALT, uric acid, cholesterol, amylase, and trypsin compared to the control group (D1). Meanwhile, the group fed 10% BBP (D2) recorded the lowest AST and ALT levels compared to the other groups (D1, D3, and D4). Additionally, the group fed 20% BBP (D3) exhibited the lowest values of total protein, albumin, A/G ratio, amylase, and trypsin among all tested groups.

Table 6. Blood parameters of the different experimental groups

Item	Zero% BBP Control	Replace YC by BBP at different levels			SEM	Sign. P<0.05
		10% BBP	20% BBP	30% BBP		
	D_1	D_2	D_3	D_4		
Total protein (g/dl)	2.47[ab]	2.36[b]	2.32[b]	2.60[a]	0.040	*
Albumin (g/dl)	1.24[ab]	1.08[b]	1.05[b]	1.32[a]	0.042	*
Globulin (g/dl)	1.23	1.28	1.27	1.28	0.015	NS
Albumin: globulin ratio	1.01	0.84	0.83	1.03	0.038	NS
Liver function						
AST (U/L)	51[cd]	46[d]	92[a]	70[b]	5.569	*
ALT (U/L)	15.05[b]	14.75[b]	17.05[a]	18.40[a]	0.493	*
Kidneys function						
Uric acid (mg/dl)	1.14c	1.54[a]	1.47[a]	1.32[b]	0.049	*
Creatinine (mg/dl)	0.21	0.24	0.25	0.21	0.010	NS
Other parameters						
Cholesterol (mg/dl)	59.85[b]	90.70[a]	101.95[a]	100.00[a]	5.642	*
Amylase (U/L)	88.90[ab]	79.60[b]	78.35[b]	94.00[a]	2.656	*
Trypsin (ng /ml)	1.05[ab]	1.01[ab]	0.91[b]	1.25[a]	0.050	*
Bilirubin(mg/dl)	0.35	0.35	0.35	0.35	0.012	NS

BBP: Biscuits by-product, Y.C: Yellow corn, a, b, c and d: Means in the same row having different superscripts differ significantly (P<0.05). SEM: Standard error of mean, NS: Not significant *: Significant at P<0.05. AST: Aspartate aminotransferase. ALT: Alanine aminotransferase.

Fish body composition of different experimental groups

Data presented in Table (7) show that the Nile tilapia fed diets containing biscuit by-product (BBP) exhibited a significant ($P< 0.05$) increase in body composition parameters, including dry matter (DM), crude protein (CP), and ash content. Conversely, the levels of moisture, organic matter (OM), ether extract (EE), and gross energy content significantly ($P< 0.05$) decreased compared to the control group.

Table 7. Fish body composition of initial and different experimental groups fed tested diets

Item	Body composition of initial fish	Zero% BBP Control	Replace YC by BBP at different levels			SEM	Sign. P<0.05
			10% BBP	20% BBP	30% BBP		
		D_1	D_2	D_3	D_4		
Moisture	75.36	74.12^{a}	73.95^{a}	73.76^{b}	73.45^{c}	0.078	*
Dry matter (DM)	24.64	25.88^{c}	26.05^{c}	26.24^{b}	26.55^{a}	0.078	*
Chemical analysis on DM basis		***Chemical analysis on DM basis***					
Organic matter (OM)	84.71	85.64^{a}	85.24^{b}	85.17^{bc}	85.05^{c}	0.071	*
Crude protein (CP)	59.13	62.43^{c}	62.96^{b}	63.19^{b}	63.50^{a}	0.124	*
Ether extract (EE)	25.58	23.21^{a}	22.28^{b}	21.98^{bc}	21.55^{c}	0.192	*
Ash	15.29	14.36^{c}	14.76^{b}	14.83^{ab}	14.95^{a}	0.071	*
Gross energy kcal/ 100g	574.54	570.90^{a}	565.16^{b}	563.64^{bc}	561.35^{c}	1.115	*
Gross energy cal/ g DM	5.7454	5.7090^{a}	5.6516^{b}	5.6364^{bc}	5.6135^{c}	0.011	*

BBP: Biscuits by-product. Y.C: Yellow corn. a, b and c: Means in the same row having different superscripts differ significantly ($P<0.05$). SEM: Standard error of mean. NS: Not significant. *: Significant at $P<0.05$.

Energy retention (ER)% and protein productive value (PPV)%

Results presented in Table (8) indicate that the incorporation of biscuit by-product (BBP) at different levels in the Nile tilapia diets led to a significant ($P< 0.05$) increase in energy retention percentage (ER%) and protein productive value (PPV%) compared to the control group (D1). Specifically, ER% improved by 16.94, 33.95, and 45.14% in groups D2, D3, and D4, respectively, relative to D1. Similarly, PPV% values significantly ($P< 0.05$) increased by 51.07, 53.09, and 54.46% for the same groups compared to the control.

Table 8. Energy retention (ER) and protein productive value (PPV) % of different experimental groups

Item	Zero% BBP Control	Replace YC by BBP at different levels			SEM	Sign. P<0.05
		10% BBP	20% BBP	30% BBP		
	D_1	D_2	D_3	D_4		
Initial weight (IW), g	181	180	182	181	0.326	NS
Final weight (FW), g	236^b	272^a	275^a	278^a	5.822	*
Calculation theenergy retention						
Energy content in final body fish (cal / g)	5.7090^a	5.6516^b	5.6364^{bc}	5.6135^c	0.011	*
Total energy at the end in body fish (E)	1347^b	1537^a	1550^a	1561^a	30.43	*
Energy content in initial body fish (cal / g)	5.7454					
Total energy at the start in body fish (E_0)	1040	1034	1046	1040	13954	NS
Energy retained in body fish ($E-E_0$)	307^b	503^a	504^a	521^a	30.88	*
Energy of the feed intake (Cal / g feed)	4.562	4.559	4.557	4.554	-	-
Quantity of feed intake	438^b	475^a	470^a	482^a	6.134	*
Total energy of feed intake (EF)	1998^b	2166^a	2142^a	2195^a	27.66	*
Energy retention (ER) %	15.37^b	23.22^a	23.53^a	23.74^a	1.244	*
Calculation the protein productive value (PPV) %						
Crude protein % in final body fish	62.43^c	62.96^b	63.19^b	63.50^a	0.124	*
Total protein at the end in body fish (PR_1)	147.33^b	171.25^a	173.77^a	176.53^a	3.950	*
Crude protein % in initial body fish	59.13					
Total protein at the start in body fish (PR_2)	107.03	106.43	107.62	107.03	0.194	NS
Protein Energy retained in body fish (PR_3) = (PR_1 – PR_2)	40.30^b	64.82^b	66.15^b	69.50^b	3.987	*
Crude protein in feed intake (CP %)	29.58	29.68	29.79	29.90	-	-
Total Protein intake (PI), g	129.56^b	140.98^a	140.01^a	144.12^a	1.819	*
Protein productive value (PPV) %	31.11^b	45.98^a	47.25^a	48.22^a	2.431	*

BBP: Biscuits by-product. Y.C: Yellow corn. a, b and c: Means in the same row having different superscripts differ significantly (*P*<0.05). SEM: Standard error of mean. NS: Not significant. *: Significant at *P*<0.05.

. **Economic evaluation of different experimental groups**

The results of the economic evaluation presented in Table (9) show that replacing yellow corn with biscuit by-product (BBP) in the feed formulation led to a reduction in feed cost. The cost decreased from 21.295 LE/kg in the control diet (D1) to 20.745, 20.195, and 19.645 LE/kg for the diets containing 10, 20, and 30% BBP (D2, D3, and D4), respectively. Moreover, the net improvement in economic efficiency was 34.27, 34.67, and 34.65% for D2, D3, and D4, respectively, compared to the control group that received the diet without BBP.

Table 9. Economical evaluation of different experimental groups

Item	Zero% BBP Control	Replace YC by BBP at different levels		
		10% BBP	20% BBP	30% BBP
	D_1	D_2	D_3	D_4
Costing of kg feed (LE)	**21.295**	**20.745**	**20.195**	**19.645**
Relative to control (%)	**100**	**97.42**	**94.83**	**92.25**
Feed conversion ratio (FCR)	**7.96**	**5.16**	**5.05**	**4.97**
Feeding cost (LE) per (Kg weight gain)	**169.51**	**107.04**	**101.98**	**97.64**
Relative to control (%)	**100**	**63.15**	**60.16**	**57.60**
Net improving in feeding cost (%)	**Zero**	**34.27**	**34.67**	**34.65**

BBP: Biscuits by-product, Y.C: Yellow corn, LE.: Egyptian pound, Diet formulation calculated according to the local prices at year 2023as presented in Table (1). Feed cost (L.E) FCR×FI. Cost per Kg diet.

DISCUSSION

The biscuit by-product (BBP) used in this study had the following proximate composition on a dry matter basis: 96.82% dry matter (DM), 10.22% crude protein (CP), 2.56% crude fiber (CF), 8.83% ether extract (EE), 69.27% nitrogen-free extract (NFE), and 9.12% ash. Gross energy (GE) was 4,388 kcal/kg DM, metabolizable energy (ME) was 359.71 kcal/kg DM, and the protein-to-energy ratio was 28.41mg CP/kcal ME. Compared to yellow corn, BBP had higher DM, CP, CF, EE, and protein-to-energy ratio, whereas yellow corn had higher organic matter (OM), NFE, GE, and ME.

Arthur (1975) reported that biscuit waste had slightly higher CP and ash content than maize, while maize had higher fiber content. The lower fiber and higher protein levels in biscuit waste may enhance feed intake and weight gain. Similarly, **Longe (1987)**

reported CP of 10.80% and 4.70 MJ/kg energy in biscuit waste. **Aderolu *et al.* (2011)** found that biscuit waste and maize used in *Clarias gariepinus* diets had similar CP levels (10.01% vs. 9.77%), but differed slightly in other components.

The experimental diets in this study were isonitrogenous and isocaloric, with CP ranging from 29.58 to 29.90%, GE from 4,554 to 4,562 kcal/kg DM, ME from 362.66 to 363.17 kcal/kg DM, and protein-to-energy ratios from 81.45 to 82.45mg CP/kcal ME—meeting the nutritional requirements for the Nile tilapia.

Growth performance indicators (final weight, total body weight gain, average daily gain, and specific growth rate) improved significantly ($P< 0.05$) when yellow corn (30% of the control diet) was replaced with BBP at 10, 20, or 30% inclusion (D2–D4). Survival rate in the control group (D1) was 93.33% (mortality 6.67%), whereas all BBP-fed groups achieved 100% survival with zero mortality.

These results agree with **Costa *et al.* (2017)**, who found that coconut biscuit residue improved final weight and SGR in tilapia fingerlings when used as a maize substitute. Although weight gain and survival rates showed no significant differences among treatments, SGR and protein retention rate improved with increasing biscuit residue inclusion. Other studies **(Signor *et al.*, 2007; Tiamiyu & Solomon, 2007; Alegbeleye *et al.*, 2008; Lasisi *et al.*, 2008; Adeyemo *et al.*, 2013; Agbebi *et al.*, 2013a)** have demonstrated that tilapia and other species can effectively utilize alternative starchy feed ingredients, though optimal replacement levels vary by ingredient and processing method.

BBP inclusion also significantly ($P< 0.05$) affected feed utilization metrics—feed intake (FI), feed conversion ratio (FCR), crude protein intake (CPI), and protein efficiency ratio (PER)—with improvements observed at all replacement levels. Blood parameters were also significantly influenced, except for globulin, albumin-to-globulin ratio, creatinine, and bilirubin ($P> 0.05$). Fish fed 30% BBP (D4) had the highest total protein, albumin, globulin, glucose, AST, ALT, uric acid, cholesterol, amylase, and trypsin values, while those fed 10% BBP (D2) recorded the lowest AST and ALT.

The observed biochemical responses align with the studies of **Raiza-Paiva *et al.* (2000)**, **Joshi *et al.* (2002)**, **Omitoyin (2006)** and **Authman *et al.* (2021)**, who emphasized that hematological and biochemical indices are key indicators of fish health and can reflect dietary effects.

Carcass composition analysis revealed significant ($P< 0.05$) increases in DM, CP, and ash, and decreases in moisture, OM, EE, and GE in BBP-fed groups compared to the control, supporting findings by **Aderolu *et al.* (2011)** and **Costa *et al.* (2017)** elucidating that biscuit residues can enhance protein retention and carcass quality.

Energy retention (ER%) improved by 16.94, 33.95, and 45.14% in D2, D3, and D4, respectively, while protein productive value (PPV%) rose by 51.07, 53.09, and 54.46% over the control. This is consistent with the outcomes of **Goda *et al.* (2012)** and **Abo-State *et al.* (2021)**, who reported that cost-effective diets can improve nutrient utilization efficiency.

Economically, BBP inclusion reduced feed cost from 21.295 LE/kg in the control diet to 20.745, 20.195, and 19.645 LE/kg in D2, D3, and D4, respectively, with net profit gains exceeding 34% in all BBP-fed groups. These findings align with previous studies **(Olomu, 1995; Sucharita *et al.*, 1998; Tharwat, 1999; Zahari & Alimon, 2006; Ajasin *et al.*, 2010; Aderolu *et al.*, 2011; Adeyemo *et al.*, 2013; Agbebi *et al.*, 2013b; Abareethan & Amsath, 2015; Azevedo *et al.*, 2015; Omoikhoje *et al.*, 2017)** recommending the use of non-conventional, low-cost feed ingredients to reduce production expenses without compromising performance.

CONCLUSION

Based on the obtained results, it can be concluded that, under the conditions of the present study, incorporating biscuit by-products (BBP) as an alternative energy source to yellow corn, traditionally the main energy component, led to notable improvements in the Nile tilapia performance. Replacing yellow corn with BBP enhances growth performance, feed utilization, and feed conversion ratio. It also significantly ($P< 0.05$) reduced the levels of AST and ALT. Furthermore, the crude protein content in fish body composition increased, along with energy retention percentage (ER%) and protein productive value (PPV%). Feed formulation costs decreased, resulting in a net improvement in feeding cost efficiency. Importantly, replacing maize with biscuit waste at graded levels up to 100% showed no adverse effects on fish health.

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