Scientific Research Publishing

Food and Nutrition Sciences, 2026, 17(11), 1113-1124
https://www.scirp.org/journal/fns
ISSN Online: 2157-9458
ISSN Print: 2157-944X

A Comparative Study of Gelatinized Starch and Predigested Starch on Growth Performance, Body Composition and Production Cost of Tilapia *Oreochromis niloticus* (Linnaeus, 1758)

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How to cite this paper: Yéo, G.M., Djeke, P.S., Ake, A., Blé, M.C. and Dabonné, S. (2026) A Comparative Study of Gelatinized Starch and Predigested Starch on Growth Performance, Body Composition and Production Cost of Tilapia *Oreochromis niloticus* (Linnaeus, 1758). *Food and Nutrition Sciences*, **17**, 1113-1124.
https://doi.org/10.4236/fns.2026.1711066

Received: January 28, 2026
Accepted: November 13, 2026
Published: November 16, 2026

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Abstract

The objective of this study was to evaluate the energy contribution of two modified starches (gelatinized and predigested) in fish. Four iso-energetic diets based on maize flour, native starch, gelatinized starch, and predigested starch were fed to juvenile tilapia for 56 days in glass aquaria. The results showed a greater weight gain with the modified starches. However, gelatinized starch resulted a significantly higher weight gain (46.45 g) compared to predigested starch (40.83 g). In contrast, there was no a significant difference in the specific growth rate ($p > 0.05$). Regarding feed utilization, the protein efficiency ratio remained constant for the diets based on these two modified starches. The body composition of fish fed with the gelatinized starch diet has higher levels of protein (15.15% wet weight) and phosphorus (5.50%). Economically, the cost to produce 100 g of weight gain is lower with the gelatinized starch diet (87.79 XOF) compared to the predigested starch diet (93.95 XOF). In conclusion, it can be estimated that gelatinized starch allows for better growth and a lower production cost than predigested starch.

Keywords

Carbohydrates, Nile Tilapia, Gelatinization, Growth, Predigestion

1. Introduction

Aquaculture is the best possible alternative to compensate for the decline in fish

stocks. Its contribution to fish production for human consumption is estimated at 51% [1]. However, in some regions of Africa, aquaculture production remains largely insufficient to meet an ever-growing demand [2] [3]. Some authors [4] [5] consider feed to be one of the main obstacles to the development of aquaculture in Africa. In formulated fish feed, fishmeal is the primary ingredient due to its high content of protein and amino acid necessary for growth [6]. However, fishmeal is expensive and scarce. Therefore, using fishmeal is not a sustainable long-term feeding strategy because it will lead to the decline or extinction of certain forage fish species [7]. Replacing this aquatic resource has therefore become imperative to preserve certain species and reducing feed costs. To reduce feed costs, replacing fishmeal with other, less expensive, non-conventional sources has been considered for several years [8]. Several studies have therefore been conducted on the potential of various raw materials to partially or completely replace fishmeal [9] [10]. Consequently, plant-based materials rich in carbohydrates have also been tested to replace some of the protein energy from fishmeal with carbohydrate energy from plants [11] [12]. Indeed, carbohydrates appear to be important in many fish species, they promote growth and, protein utilization [13]. Carbohydrates, referred to as macronutrients due to their essential contribution to nutrition, constitute the most abundant and expensive energy source for animal farming. However, the inclusion rate of carbohydrate in fish feed remains limited in some fish species, given the low digestibility of carbohydrates by fish [14]. However, according to [15], this rate can be increased by incorporating digestible carbohydrates and a high lipid content, this nutritional strategy used to conserve protein without compromising fish growth. Some authors assert that the degree of carbohydrate polymerization affects its digestibility in fish. Thus, monosaccharides are reportedly more digestible than dextrin, while native starches have relatively low digestibility [16]. Any technological treatment that reduces the molecular weight of carbohydrates improves their digestibility in fish [17] [18]. The treatment of modifying starch structure can be physical (gelatinization or extrusion), chemical (esterification or oxidation), or enzymatic (amylase). This study aimed to determine the influence of two types of modified starch on the zootechnical performance of Nile tilapia (*Oreochromis niloticus*).

2. Materials and Methods

2.1. Experimental Design and Fish

This study was carried out in the hatchery of the center for Research oceanological, Côte d'Ivoire. The device used were constituted of 40 glass aquaria (containing 50 L of water) in a closed-circuit system. 12 glass aquaria were used, 3 glass aquaria per diet. An electric motor pump ensured a constant flow of well-aerated tap water. Water was filtered by settling and a 30% daily exchange of water. Every day, at 7 h and 30 min, before feeding, temperature (28.1˚C - 28.4˚C), dissolved oxygen (6.2 - 6.9 mg/L) and pH (7.2 - 7.3) were measured with a multi parameter (BANTE 900P).

The juvenile *Oreochromis niloticus* (34.85 ± 2.03 g) used in this experiment came from the ponds of the Experimental Station of Center. Two hundred and forty (240) juveniles were collected and acclimated to the experimental conditions for two weeks. 60 fish were used for a diet at a rate 20 fish per glass aquaria. The density is 2.5 fish per liter.

2.2. Process of Gelatinization of Starch

Corn starch was gelatinized according to the technique defined by [19] modified by [18]. Starch maize (10% w/w 0.5 kg of starch in 5 kg of distilled water) were gelatinized at 70˚C for 30 min using a reactor with a paddle rotated at a fixed speed of 150 rpm. The starch slurry was heated from room to 70˚C and maintained at 70˚C for 30 min. Then, sample was freeze-dried (Biobase Model BK-FD 1 OP) for 24 h at −40˚C and 0.37 mbar vacuum pressure and heated up to 20˚C. The flour obtained was grounded and subdued with a sieve (ϕ = 1mm). The degree of gelatinization was 42.46%.

2.3. Process of Enzymatic Predigestion of Starch

Starch was predigested at the Biocatalysis and Bioprocesses Laboratory of Nangui Abrogoua University, Côte d'Ivoire. The digestive juice of the snail *Archachatina ventricosa* was extracted according to the method described by [20] and used as an enzyme source for starch predigestion. The process was carried out in an incubator at 37˚C. The mixture consisted of 10 mL of enzyme extract, 5 L (10% w/v) of starch heated to 100˚C for 5 minutes, and acetate buffer at pH 4.5. Incubation lasted 10 minutes, after which the predigested starch was collected and dried in a ventilated oven at 20˚C. The degree of predigestion of starch was 64.82%.

2.4. Experimental Diets and Condition

The raw materials such as fish meal, soybean meal, wheat bran, maize, and cassava used in this study were purchased at the local market of Abidjan. All ingredients were ground to a suitable SIZE and mixed in a commercial mixer (KENWOOD CHEF). Four iso-energetic diets were prepared using a kitchen meat grinder with a 3 mm diameter (Panasonic MK-G 1800P). The diets were a maize four-based diet, a native starch-based diet, a gelatinized starch-based diet, and a predigested starch-based diet (Table 1).

Table 1. Formulation and composition of the experimental diets.

	Experimental diets			
Ingredients (%)	Maize flour	Native starch	Gelatinized starch	Predigested starch
Fish meal	43	43	43	43
Soybean meal	32	32	32	32
Wheat bran	5	5	5	5
Maize flour	12	-	-	-

Continued

Native starch	-	12	-	-
Gelatinized starch	-	-	12	-
Predigested starch	-	-	-	12
Cassava starch	2	2	2	2
Fish oil	4	4	4	4
Vitamin mixture1	1	1	1	1
Mineral mixture2	1	1	1	1
Total	100	100	100	100
Proximate analysis (% DM)				
Crude protein	36.17	34.87	34.87	34.87
Total fat	9.95	9.33	9.33	9.33
Ash	11.14	10.95	10.95	10.95
Crude fiber	2.57	2.18	2.18	2.18
Carbohydrates	31.42	33.83	33.83	33.83
Digestible energy (kJ/g)	13.88	13.67	13.67	13.67
Ratio P/DE (mg protein/kJ)	26.06	25.51	25.51	25.51

DM: Dry matter; [1]Per kg premix: cobalt 20 mg, iron 17,600 mg, iodine 2000 mg, copper 1600 mg, zinc 60,000 mg, manganese 10,000 mg, selenium 40 mg; [2]Per kg premix: vitamin A1 760,000 IU, vitamin D3 880,000 IU, vitamin E 22,000 mg, vitamin B1 4400 mg, vitamin B2 5280 mg, vitamin B6 4400 mg, vitamin B 1 236 mg, vitamin C 151,000 mg, vitamin K 4400 mg, vitamin P 35,200 mg, folic acid 880 mg, choline chloride 220,000 mg, pantothenic acid D 14,080 mg.

After the acclimation period, the fish were fed till apparent satiation with the experiment diets twice daily (8 am and 4 pm) for 56 days. To quantify the exact feed intake, refused feed was siphoned out immediately, dried and weighed. Once a week, ten fish were randomly sampled in each glass aquaria to measure body weights and glass aquaria were cleaned. At the end of the experiment, the weight of each fish was recorded. Ten fish from each diet were stored at −20˚C for whole-body composition analysis.

2.5. Chemical Analysis

Chemical analysis of diets and fish was determined following the standard methods [21]. Calculation of the energetic content was done using the equivalent values of proteins, lipids, and carbohydrates [22].

2.6. Zootechnical Parameters

Survival Rate (SR), Daily Weight Gain (DWG), Specific Growth Rate (SGR), Feed Conversion Ratio (FCR), Protein Efficiency Ratio (PER) were calculated as follows:

- SR (%) = [Number of fish/Initial number of fish] × 100
- DWG (g/d) = [Final weight – Initial weight]/Duration of the experiment (days)

- SGR (%/d) = 100 × [Ln (Final weight) – Ln (Final weight)]/Duration of the experiment (days)
- FCR = Dry feed consumed/Wet weight.
- PER = Wet weight gain/Protein consumed.

2.7. Economic Evaluation

The assessment of the economic cost of the diets was made on the basis of the different prices of raw materials encountered on the local market. The price of 100 g of diet and the quantity of feed required per diet to produce 100 g of weight gain was evaluated according to the following formulas:

- $P_1 = \Sigma [R \times Z/1000]$ where

  P_1: Price of 100 g of feed formulated by experimental diet (XOF);

  R: Price of kg of raw materials (XOF);

  Z: Quantity of each raw material in 100 g of feed formulated by experimental diet (g);

- $P_2 = FCR \times P_1$

  P_2: Price of the quantity of feed needed to produce 100 g of weight gain (XOF);

  FCR: Feed conversion ratio.

2.8. Statistical Analysis

Results were statistically analyzed with a one-way analysis of variance (ANOVA) using Statistica version 7.1 software packages. Duncan's multiple range test was used to compare difference between treatments means when significant F-values were observed. All percentage were arc-sin transformed before analysis (Zar, 1984). The treatment effects were considered to be significant at $p < 0.05$.

3. Results and Discussion

3.1. Survival Rate

The survival rate at the end of the experiment is shown in **Table 2**. This rate ranged from 83.33% to 87.5%, and no significant difference was observed between the different diets ($p > 0.05$). It can be estimated that the experimental diets had no influence on survival rate. These values, ranging from 83.33% to 87.5%, are within the range considered acceptable (~75%) for tilapia farming [23]. These high rates can be attributed to the quality of the rearing environment, which remained stable across the different aquariums, and the values of the physicochemical parameters (temperature, pH, dissolved oxygen), are within the optimal ranges for tilapia farming [24]. The stability of the rearing water and also the good physiological condition of the fish indicate that the variation in fish growth is due to the quality of the feed distributed.

3.2. Growth Performance

The experimental diets differed in their carbohydrate source, corn flour, native starch, gelatinized starch, or predigested starch. Thus, the significant differences

observed in the results were related to the energy contribution of each carbohydrate source. The evolution in fish weight during the experiment is shown in **Figure 1**. During the first 21 days, the growth evolution shows similar trends. This period corresponds to the adaptation period of the fish to the new diets. This duration is longer than the 7 days observed by [25] for raising this species in aquariums. After this adaptation period, a differentiation in fish growth is noted depending on the diet. This difference could be explained by the degree of carbohydrate convertibility by the fish [4], the fish begin to digest certain formulated diets more effectively.

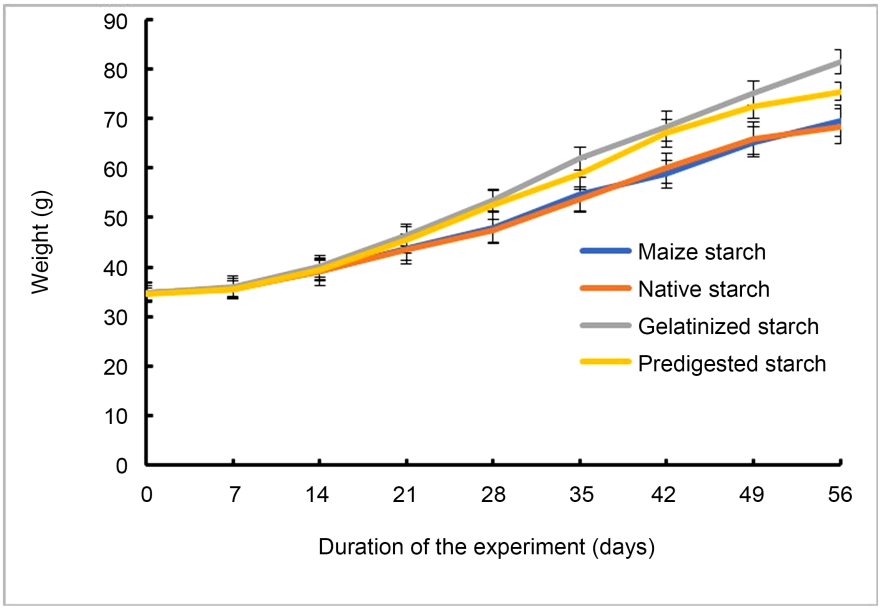


Figure 1. Evolution in weight of fish during the experiment.

The weight gain of juveniles fed the different experimental diets is illustrated in **Figure 2.** Weight gains ranged from 33.60 to 46.45 g and varied significantly according to the diet used ($p < 0.05$). Fish fed the diets based on gelatinized starch showed the greatest gains. Daily Weight Gain and Specific Growth Rate are presented in **Table 2**. Diets based on gelatinized starch and predigested starch have better values than diets based on maize flour and native starch. This result indicates that gelatinization and predigestion improve carbohydrate energy utilization in fish. Generally, modifying starch structure generally leads to increased digestibility [26]; however, its implications for growth, physiology, and waste and disease management can depend on the species, starch type, and degree of gelatinization [27]. Some studies have shown that gelatinized starch enhances fish growth compared to native starch [18] [28]. Regarding the two modified starches, gelatinized starch resulted in significantly higher growth (DWG = 0.83 g/d) compared to predigested starch (DWG = 0.73 g/d) at the 5% threshold. This result shows that gelatinized starch was better utilized than predigested starch. This difference in performance may be related to the levels of simple sugars released in the predigested,

gelatinized starch meal after the modification processes. [29] observed poor growth in Nile tilapia (*O. niloticus*) fed a diet rich in simple sugars (glucose, fructose, sucrose) compared to tilapia fed complex sugars (maltose, starch). Ingestion of high levels of simple sugars causes persistent postprandial hyperglycemia and metabolic disturbances often associated with reduced growth rates in fish [14] [30]. The high level of simple sugars can be explained by the process of predigested starch, which requires prior heating of the native starch (gelatinization) before adding amylases to breakdown complex sugars into simple sugars.

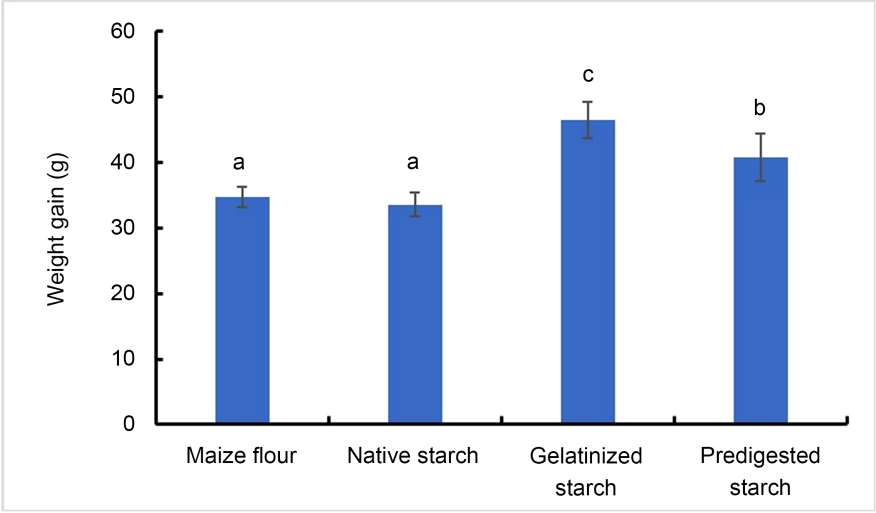


Figure 2. Weight gain after 56 days of the experiment.

Table 2. Growth performance of tilapia *O. niloticus* after 56 days.

	Experimental diets			
Parameters	Maize flour	Native starch	Gelatinized starch	Predigested starch
Survival rate (%)	83.33 ± 14.43^{a}	86.76 ± 12.58^{a}	86.76 ± 12.58^{a}	83.33 ± 14.43^{a}
Initial weight (g)	34.85 ± 1.66	34.82 ± 1.80	34.90 ± 1.42	34.62 ± 2.03
Final weight (g)	69.56 ± 3.25^{a}	68.42 ± 3.57^{a}	81.35 ± 2.74^{c}	75.45 ± 1.90^{b}
DWG (g/d)	0.62 ± 0.03^{a}	0.60 ± 0.03^{a}	0.83 ± 0.06^{c}	0.73 ± 0.06^{b}
SGR (%/d)	1.23 ± 0.01^{ab}	1.21 ± 0.02^{a}	1.51 ± 0.11^{c}	1.39 ± 0.14^{bc}

Means in a row with different superscripts significantly ($p < 0.05$). DWG: Daily Weight Gain; SGR: Specific Growth Rate; d: day.

3.3. Feed Utilization Parameters

The Feed Conversion Ratio (FCR) and Protein Efficiency Ratio (PER) are shown in **Figure 3**. The FCR ranged from 1.76 to 2.28, with the highest value obtained with the native starch-based feed ($p < 0.05$). For the Protein Efficiency Ratio values varied from 1.26 to 1.64. PER showed no significant difference ($p > 0.05$) between gelatinized starch and predigested starch. This result indicates that the proteins in the diets were used with the same efficiency for growth; thus, it can be estimated that a large portion of the energy provided by carbohydrate sources was directed

to maintenance, reproduction, and other activities [31].

Similar observations were reported by [32], indicating better utilization of carbohydrates from gelatinized starch in catabolic metabolism to support energy expenditure in fish, rather than being retained (fixed) to contribute to fish growth such as proteins.

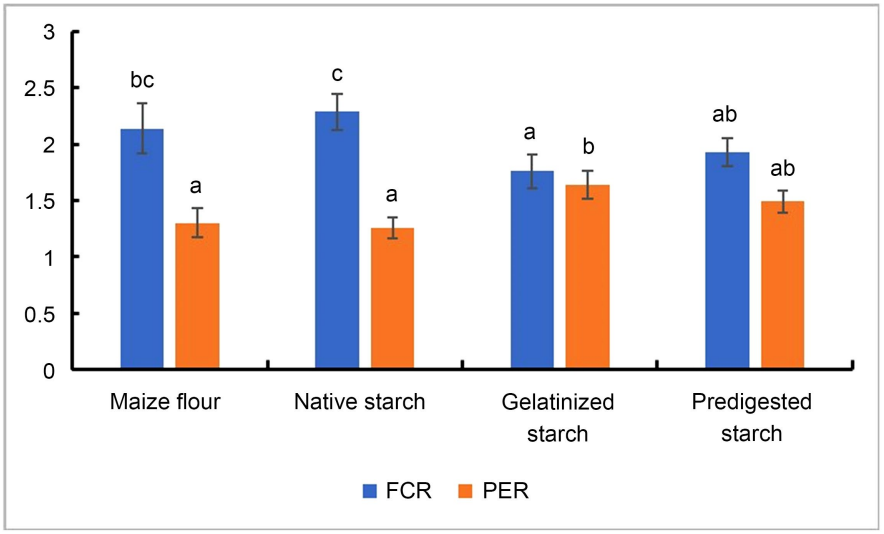


Figure 3. Feed Conversion Ratio (FCR) and Protein Efficiency Ratio (PER) of experimental diets.

3.4. Body Composition

The proximate of body composition is presented in **Table 3**. Moisture content, ash content, and gross energy show no significant difference between the diets ($p > 0.05$). However, protein and lipid contents varied depending on the diet used. The protein levels were higher (15.15% wet weight) in fish fed the gelatinized starch-based diet, but there was no significant difference in lipid levels between diets based on corn, gelatinized starch, and predigested starch. This result highlights efficient protein retention for fish growth [33], which may explain the improved growth with gelatinized starch. This result was reflected in a higher phosphorus content in the mineral composition of the body of fish fed with this gelatinized starch.

Table 3. Body composition of tilapia *O. niloticus*.

	Experimental diets			
Parameters	Maize flour	Native starch	Gelatinized starch	Predigested starch
Moisture (% WW)	76.99 ± 0.35a	76.97 ± 1.23a	75.3 ± 1.34a	75.35 ± 0.84a
Crude protein (% WW)	13.8 ± 0.04a	13.8 ± 0.28a	15.15 ± 0.21c	14.11 ± 0.28b
Crude lipid (% WW)	5.03 ± 0.25b	4.81 ± 0.33a	5.66 ± 0.34b	5.27 ± 0.24b
Ash (% WW)	3.46 ± 0.42a	3.77 ± 0.81a	3.45 ± 0.67a	3.25 ± 0.13a
Energy (kJ/g)	5.14 ± 0.19a	5.05 ± 0.16a	5.64 ± 0.03a	5.57 ± 0.19a

Continued

Phosphorus (% DM)	4.52 ± 0.78b	4.08 ± 0.65a	5.50 ± 0.98c	4.52 ± 1.34b
Calcium (% DM)	0.08 ± 0.03a	0.08 ± 0.01a	0.1 ± 0.01a	0.3 ± 0.02a
Potassium (% DM)	0.03 ± 0.00a	0.03 ± 0.01a	0.05 ± 0.01b	0.12 ± 0.02c

Means in a row with different superscripts significantly ($p < 0.05$). WW: Wet Weight; DM: Dry Matter.

3.5. Production Costs

Table 4 shows the production costs per 100 g of weight gain. Diets based on gelatinized starch result in lower costs (87.79 XOF) per 100 g of weight gain compared to diets based on pregelatinized starch (93.95 XOF). This is explained by its very low feed conversion ratio (1.76) compared to the ratios of the other experimental diets. Thus, gelatinized starch offers better economic profitability. The lower the feed conversion ratio of a feed, the better the feed efficiency and the lower the cost of fish production [4].

Table 4. Economic evaluation of experimental diets.

Ingredients	Cost (XOF/kg)	Experimental diets			
		Maize flour	Native starch	Gelatinized starch	Predigested starch
Fish meal	600	25.8	25.8	25.8	25.8
Soybean meal	340	10.88	10.88	10.88	10.88
Wheat bran	120	0.6	0.6	0.6	0.6
Maize flour	300	3.6	-	-	-
Native starch	350	-	4.2	-	-
Gelatinized starch	500	-	-	6	-
Predigested starch	400	-	-	-	4.8
Cassava starch	300	0.6	0.6	0.6	0.6
Fish oil	1000	4	4	4	4
Vitamin mixture	1000	1	1	1	1
Mineral mixture	1000	1	1	1	1
Cost of feed (XOF/100g)		47.48	48.08	49.88	48.68
Cost of fish (XOF/100g weight gain)		101.61	109.62	87.79	93.95

4. Conclusion

The objective of this study was to compare the efficiency of carbohydrate intake from gelatinized starch and predigested starch. The results showed an improvement in energy intake with both modified starches compared to maize flour and native starch. Regarding the two modified starches, gelatinized starch resulted in better fish growth and lower production costs compared to predigested starch. In terms of body composition, Protein and phosphorus content were also higher in the fish fed with gelatinized starch.

Acknowledgements

The authors are grateful to Center for Research Oceanological for the experimental design.

Author Contributions

Concept and design of study: Y.G.M.; Data acquisition: Y.G.M., D.P.S. and A.A.; Data analysis and interpretation: Y.G.M. and D.P.S.; Drafting manuscript: Y.G.M., D.P.S. and A.A.; Critical revision of manuscript: B.M.C. and D.S.; Final approval: B.M.C. and D.S. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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