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Carbon source selection for efficient biofloc-based culture of Pearlspot, *Etroplus suratensis* (Bloch, 1790)

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ABSTRACT

Biofloc technology (BFT) is increasingly recognised as a sustainable approach to intensive aquaculture, improving water quality while serving as a supplementary feed source through microbial biomass. The present study evaluated the efficacy of five locally available carbon sources—jaggery, sugar, wheat bran, corn flour, and tapioca flour in supporting biofloc development for the culture of pearlspot (*Etroplus suratensis*). Maintained a semi-intensive outdoor BFT system over 56 days, and parameters such as water quality, growth performance, floc volume, microbial load, and proximate composition of biofloc and fish were assessed. Among the tested carbon sources, jaggery significantly enhanced biofloc quality, maintained optimal water conditions, increased Total Plate Counts (14.15 ± 0.03) $\times 10^3$, and yielded the highest protein (37.40 ± 0.11) and lipid levels (4.16 ± 0.05) in both biofloc and fish muscle tissue. Fish reared in the jaggery treatment showed superior growth performance, FCR (0.9±0.05), and survival. These findings suggest that jaggery is an effective and affordable carbon source for optimising biofloc-based pearlspot culture systems, contributing to more sustainable aquaculture practices.

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1. Introduction

One of the major challenges in intensive aquaculture systems is the deterioration of water quality due to the accumulation of uneaten feed and excretory products, which leads to elevated nitrogenous waste levels. This not only affects the health and growth of cultured organisms but also contributes to environmental pollution. Biofloc technology (BFT) has gained recognition as a sustainable approach to address water quality issues by promoting the growth of microbial communities that convert toxic nitrogen compounds into microbial biomass (Hargreaves, 2006). These microbial flocs serve as a supplemental feed source, rich in protein, lipids, vitamins, and bioactive compounds, enhancing the nutrition and health of cultured species (Emerenciano et al., 2017). The effectiveness of BFT largely depends on the availability of suitable carbon sources to maintain an optimal carbon-to-nitrogen (C: N) ratio in the system. One of the major advantages of the biofloc technology is its minimal water exchange requirement, which significantly reduces environmental impact and alleviates stress on cultured organisms (De Schryver et al., 2008; Crab et al., 2012; Nevejan et al., 2018). The microbial aggregates—commonly referred to as flocs—are composed of heterotrophic bacteria, zooplankton, uneaten feed residues, and organic detritus. These flocs are nutritionally rich, particularly in protein, and contribute substantially to the dietary protein intake of cultured species. As a result, they offer the potential to reduce reliance on expensive formulated feeds, thereby lowering the overall cost of aquaculture production (Suloma, 2013; Wasielesky et al., 2013; Khalil et al., 2016; El-Husseiny et al., 2017; Zidan et al., 2017; El-Shaifey, 2018).

Carbon sources are crucial in determining the formation, structural integrity/solubility, microbial composition, and nutritional attributes of bioflocs (Hollender et al., 2002; Oehmen et al., 2004). The success of biofloc development is closely linked to the type, quality, and carbon-to-nitrogen (C: N) ratio of the added carbon source (Avnimelech, 2007). A wide range of carbohydrate inputs—including glucose, molasses, cassava meal, cellulose powder, tapioca flour, starch, wheat flour and jaggery—have been utilized to stimulate microbial floc formation in various aquaculture systems, both intensive and extensive (Avnimelech, 2007; Asaduzzaman et al., 2008, 2009a, 2009b, 2010a, 2010b; Anitha et al., 2025a, 2025b). Importantly, the nature of the carbon source can significantly influence the biochemical profile of biofloc (Hollender et al., 2002; Oehmen et al., 2004; Susitharan et al., 2021; Jackqulinwino et al., 2024). Consequently, an ideal carbon source should be economically viable, safe, readily available, and compatible with the specific aquaculture system and the cultured species. BFT is particularly advantageous for fish species that can directly consume microbial flocs as a nutritional source. Pearlspot (*Etroplus suratensis*), the largest among the Indian cichlids and native to peninsular India and Sri Lanka, is one such species. Its high tolerance to salinity fluctuations, omnivorous diet, and robust market demand make it a popular food fish. Growing interest from domestic consumers, the tourism sector, and international markets underscores its significant potential to advance sustainable aquaculture practices (Padmakumar et al., 2002; Susitharan et al., 2021).

Numerous studies have explored the effects of various carbon sources on water quality and the growth performance of aquatic species within biofloc systems. For example, *Penaeus monodon* exhibited enhanced growth and immune response when cultured using rice flour rather than beet molasses (Kumar et al., 2017). Similarly, the use of readily degradable carbon sources, such as molasses and dextrose, improved water quality in *Litopenaeus vannamei* compared to less degradable substrates, such as rice bran (Serra et al., 2015). Glycerol-based bioflocs enriched with bacillus spores also led to higher protein content and survival rates in *Macrobrachium rosenbergii* than glycerol or glucose alone (Crab et al., 2010).

A carbon source blend consisting of 60% molasses, 20% corn flour, and 20% wheat bran significantly enhanced enzyme activity and growth in juvenile *L. vannamei* (Wang et al., 2016). Caipang et al. (2015) reported that sweet potato effectively reduced total ammonia nitrogen (TAN), nitrite, and nitrate levels, whereas wheat flour improved feed conversion ratios in tilapia. Although Silva et al. (2017) observed no significant growth differences among carbon sources in tilapia, molasses and sugar promoted superior biofloc development. El-Shafiey et al. (2018) also found that cellulose was effective in improving water quality and supporting fish growth in BFT systems. In the current study, locally available and cost-effective carbon sources—including tapioca flour, wheat bran, corn flour, jaggery, and sugar—were selected to induce biofloc formation. Their efficacy was evaluated in a semi-intensive BFT setup for *E. suratensis* to assess their roles in biofloc development, water quality enhancement, and overall fish performance under controlled conditions.

2. Materials and Methods

2.1 Experimental Setup

The experiment was conducted at the Department of Aquatic Biology and Fisheries, Kariavattom Campus, University of Kerala, India. Juvenile *Etroplus suratensis* (Pearlspot cichlid) was selected for experimental research as this developmental stage exhibits maximum physiological development, heightened metabolic sensitivity, and increased vulnerability to environmental and nutritional factors. Before the start of the experiment, approximately 300 healthy *E. suratensis* seedlings with an initial weight of 1.5 ± 0.11 g were procured from Ayiramtheng Government Fish hatchery and acclimatised for 14 days in a circular tank (volume: 1000 L). During the acclimatisation period, the fish were fed a commercial diet containing 35% crude protein at 3% of their body weight, three times daily. The tanks were continuously aerated, and the water temperature was maintained at 29 ± 1 °C. A completely randomised design was used with five treatments, each with three replicates, across 15 circular tanks (volume: 80 L). The tanks were set up outdoors and covered with UV-stabilised sheets to ensure sunlight availability while preventing rainwater intrusion. Aeration was provided continuously via air stones connected to a centralised air pump (Hailea HAP 120). Fish were stocked at a density of 20 individuals per tank. Five locally available carbohydrate sources—tapioca flour, wheat bran, corn flour, jaggery, and sugar were used to promote biofloc development. All carbon sources, except wheat bran (collected from a local flour mill), were purchased from the local market. Biofloc development occurred naturally at a carbon-to-nitrogen (C: N) ratio of 20, without external inputs such as inoculum, probiotics, or fermented carbohydrates. Floc formation was induced by adding a raw carbohydrate source in response to ammonia nitrogen production in each system. The quantity of carbohydrate was determined by measuring ammonia nitrogen in each system, using the calculation method by Avnimelech (1999). The trial lasted for 56 days (8 weeks).

2.2 Feeding Regime

Fish were fed twice daily (09:00 and 17:00 hrs) at 3% of their body weight/day using a commercial floating feed containing 35% crude protein. Feed amounts were adjusted biweekly based on sampling weights. Uneaten feed was monitored, and no siphoning was performed to maintain the biofloc environment unless the biofloc volume exceeded recommended levels (10 ml/l).

2.3 Water Quality Monitoring and Microbial Analysis

During the 8-week experimental period, key water quality parameters—including water temperature measured with a Celsius thermometer, pH measured with a pH meter (Eutech-PC tester 35), and total ammonia nitrogen (TAN)—were monitored daily. Additional parameters such as dissolved oxygen (DO, estimated by Winkler's method), nitrite (NO_2^-), nitrate (NO_3^-), alkalinity, and floc volume (measured using an Imhoff cone) were also recorded daily. In situ temperature and pH measurements were taken each morning at 0900 h. Water samples were collected from each tank and pooled together for analysis. Samples were transported to the laboratory within two hours of collection. TAN was analysed by the phenol-hypochlorite method, nitrite by standard colourimetric methods, and nitrate by the resorcinol method. Dissolved oxygen, nitrate, and other water-quality parameters were analysed according to the standard procedures described by APHA (1995). Total plate counts (TPC) were assessed every 28 days by collecting water samples from each tank. The TPC counts were estimated using standard plate count techniques as per APHA (1995) and expressed as colony-forming units (cfu/ml). Carbon and nitrogen contents of the different carbohydrate sources were determined using a CHN analyser.

2.4 Growth Performance

At the end of the 56-day trial, fish were harvested and measured for final Weight and Length. The following growth parameters were calculated (Bergheim, 1990):

Weight gain (g) = Final weight – Initial weight

Specific growth rate (%) = [(Ln Final weight – Ln Initial weight)/number of days] × 100

(where Ln is natural log)

Feed conversion ratio (FCR) = Feed given (g) / Weight gain (g)

Survival rate (%) = (Final number of fish / Initial number of fish) × 100

2.5 Estimation of Total Plate Count (TPC)

Water samples were collected at fortnightly intervals for TPC estimation. Following a modified protocol by Kumar et al. (2014), 200 mL of each sample was homogenised. Serial dilutions were prepared in sterile saline solution, and 0.1 ml aliquots of the appropriate dilutions were plated onto Tryptone Soya Agar (TSA) supplemented with 1.0% NaCl. Plates were incubated at room temperature for 24–48 hours, and colony-forming units (CFU) were counted to estimate TPC populations (Brackett 1992).

2.6 CHN Analysis of Carbon Sources

The carbon and nitrogen contents of the selected carbohydrate sources, tapioca flour, wheat bran, corn flour, jaggery, and sugar, were analysed using a CHNS/O analyser (PerkinElmer 2400 series 11). This analysis provided C: N ratios to assess each source's suitability for promoting biofloc formation.

2.7 Proximate Composition of Biofloc

Biofloc samples were collected from each tank using Imhoff cones and passed through a 100 µm mesh to separate larger particles. The collected floc was oven-dried at 70°C. Proximate composition was analysed using standard protocols as follows:

Protein: Lowry et al. (1951)

Lipid: Folch et al. (1957)

Ash and Crude Fibre: (AOAC, 2012)

2.8 Carbon Source Supplementation and Floc Volume Estimation

The amount of carbohydrate added was calculated based on the nitrogen input, following the guidelines of Avnimelech (1999) and Hari et al. (2004, 2006), aiming to maintain a C: N ratio of 20:1 by adding carbon at 20 times the Total Ammonia Nitrogen (TAN) concentration. Biofloc development was monitored by measuring floc volume using 1 L of culture water, which was allowed to settle in an Imhoff cone for 30 minutes.

2.9 Statistical Analysis

Statistical analysis was carried out using Microsoft Excel and SPSS (version 26). Descriptive statistics, including mean and standard deviation (SD), were computed to summarise the data. All results are expressed as Mean ± SD. ANOVA was also used to find out significant differences among groups.

3. Results and Discussion

3.1 Carbon Source

In this study, five commonly available carbon sources—wheat bran, corn starch, tapioca flour, sugar, and jaggery—were evaluated for their effectiveness in a biofloc system. Jaggery, a traditional unrefined sugar derived from sugarcane juice, is rich in minerals and energy (Singh, 2001). It is widely consumed as a sweetener and used in animal feed formulations due to its high nutritive value and affordability, making it a cost-effective alternative to raw sugar.

Table 1. Carbon and Nitrogen Composition of Selected Carbon Sources Used for Biofloc Formation

Carbon Source	Carbon (%)	Nitrogen (%)
Sugar	36.68 ± 0.50	0.01 ± 0.02
Tapioca flour	36.29 ± 0.03	0.33 ± 0.03
Corn flour	38.79 ± 0.69	1.18 ± 0.15
Wheat bran	36.52 ± 0.50	2.06 ± 0.01
Jaggery	33.90 ± 0.71	0.07 ± 0.02

The carbon (C) and nitrogen (N) composition of the five different carbon sources—sugar, tapioca flour, corn flour, wheat bran, and jaggery—was determined and is presented in Table 1. The analysis provides essential information for optimising the C: N ratio in biofloc systems, a key factor influencing microbial activity, nitrogen assimilation, and overall water quality in aquaculture (Avnimelech, 2007). The results revealed that corn flour had the highest carbon content (38.79%), followed closely by sugar (36.68%), tapioca flour (36.62%), and wheat bran (36.52%). Jaggery exhibited a slightly lower carbon concentration (33.90%), possibly due to the presence of additional minerals and organic compounds. In terms of nitrogen content, wheat bran showed the highest nitrogen level (2.06%), indicating a relatively higher protein composition. This is consistent with wheat bran's known nutrient profile, which includes significant amounts of protein and fibre.

On the other hand, sugar exhibited a trace amount of nitrogen (0.01%), followed by jaggery (0.07%), making these ideal candidates for manipulating the C: N ratio in biofloc systems. Tapioca flour and corn flour presented intermediate nitrogen values of 0.33% and 1.18%, respectively. These findings align with earlier reports suggesting that carbon sources with low nitrogen content are more suitable for biofloc formation, as they favour the proliferation of heterotrophic bacteria by promoting nitrogen assimilation from the water column (Hargreaves, 2006). High-nitrogen substrates, such as wheat bran, may reduce the effectiveness of nitrogen removal unless balanced with additional carbon. From a practical standpoint, sugar and jaggery are the most appropriate carbon sources for achieving a high C: N ratio, thereby enhancing microbial floc formation and ammonia assimilation. However, jaggery, being a semi-processed product, may offer additional micronutrients and fermentable sugars that support bacterial growth more effectively under certain conditions (Singh, 2001).

3.2 Water Quality

Water quality parameters monitored across all treatments are summarised in Table 2. Key parameters—temperature, pH, dissolved oxygen (DO), alkalinity, total ammonia nitrogen (TAN), nitrite, nitrate, and floc volume—remained within acceptable ranges for biofloc-based aquaculture systems, in agreement with guidelines (Stone & Thomforde, 2004; Stickney, 2005; Emerenciano et al., 2017). No statistically significant differences ($p > 0.05$) were observed among treatments for DO, temperature, pH, alkalinity, floc volume, or nitrite, indicating stable water conditions across different carbon sources. All carbon sources reduced TAN levels over time, indicating effective

Table 2. Physicochemical parameters of different carbon sources used in biofloc systems

Parameters	Sugar	Tapioca flour	Corn flour	Wheat bran	Jaggery	F value	P value
Temperature (°C)	30.13± 0.05	30.13±0.11	30.06±0.05	30.03±0.05	30.1±0.10	0.85	0.525
pH	7.8 ± 0.03^{c}	7.8 ± 0.01^{d}	7.89 ± 0.00^{b}	7.89 ± 0.1^{c}	7.9 ± 0.00^{a}	4.272	0.028
Alkalinity (mg/l)	189.07 ± 1.2^{c}	189.85 ± 0.79^{d}	191.23 ± 0.14^{b}	191.32 ± 0.1^{a}	191.19 ± 0.14^{c}	91.472	0.000
TAN (mg/l)	0.04 ± 0.00^{c}	0.05 ± 0.00^{b}	0.07 ± 0.01^{a}	0.04 ± 0.01^{d}	0.02 ± 0.00^{e}	22.250	0.000
Nitrite (mg/l)	0.23 ± 0.07^{a}	0.21 ± 0.01^{b}	0.18 ± 0.01^{c}	0.14 ± 0.05^{d}	0.12 ± 0.01^{e}	6.028	0.010
Nitrate (mg/l)	6.29 ± 0.33	6.16 ± 0.03	6.18 ± 0.02	6.18 ± 0.01	6.11 ± 0.03	1.037	0.435
DO (mg/l)	5.05 ± 0.03^{a}	5.01 ± 0.00^{c}	4.97 ± 0.07^{e}	5 ± 0.52^{d}	5.04 ± 0.00^{b}	3.681	0.043
FV (ml/l)	8.3 ± 0.35	6.2 ± 0.64	6.63 ± 0.56	8.1 ± 0.52	9.6 ± 0.52	3.403	0.053

Note: Values are mean±SD of three replicates, and values with different superscript letters are significantly different at $p < 0.05$

microbial assimilation of nitrogenous waste. However, variations were observed in the rate and extent of TAN reduction. Treatments supplemented with tapioca flour, corn flour, and wheat bran exhibited a slower decline in TAN levels during the initial phase of the trial. This may be attributed to the more complex carbohydrate structures in these substrates, which require longer microbial processing time. In contrast, treatments with simpler sugars, such as jaggery and sugar, led to a more rapid decline in TAN levels (Avnimelech, 2007).

Notably, treatment with jaggery consistently maintained the lowest TAN (0.02 ± 0.00 mg/l) and nitrite levels (0.12 ± 0.01 mg/l) throughout the study, suggesting enhanced microbial activity and assimilation efficiency. This aligns with reports by Khanjani et al. (2017) and Silva et al. (2017), who emphasised the importance of carbon source complexity in microbial community dynamics and biofloc formation. The higher floc volume observed in the jaggery treatment (9.6 ± 0.52 ml/l) further supports this observation, indicating more robust microbial growth and nutrient capture. Although nitrate levels showed slight variations, they remained stable across treatments, suggesting successful nitrification. The observed water quality trends indicate that readily biodegradable carbon sources, such as jaggery, enhance microbial floc formation, improve nitrogen removal efficiency, and support better water quality in biofloc systems (Singh, 2001).

3.3 Growth and Survival

The growth performance, feed utilisation, and survival of *E. suratensis* cultured in biofloc systems with various carbon sources are summarised in Table 3. Among the treatments, the jaggery-supplemented group exhibited significantly superior performance in final weight, weight gain, length gain, specific growth rate (SGR), and feed conversion ratio (FCR). This was followed by the treatment with sugar, indicating the effectiveness of readily fermentable carbon sources in promoting optimal biofloc conditions.

Fish reared under jaggery-based biofloc achieved the highest weight gain (3.29 ± 0.09 g) and length gain (1.62 ± 0.20 cm), along with the best SGR (2.06 ± 0.03%/day) and lowest FCR (0.90 ± 0.05). These improvements can be attributed to improved nutrient assimilation by microbial flocs and to enhanced water quality parameters driven by active microbial communities. The mortality rate varied across trials, potentially due to the use of different carbon sources with varying solubility rates (resulting in TSS) in water (Panigrahi et al., 2019; Serra et al., 2015). Total suspended solids were higher in biofloc systems utilising less soluble carbon sources, such as flour and bran, compared to systems using highly soluble carbon sources, such as sugar or jaggery. The survival rate was also highest in jaggery-based treatment (86 ± 3.6%), suggesting a positive correlation between biofloc quality and fish resilience. In contrast, biofloc systems incorporating tapioca flour, corn flour, and wheat bran showed relatively lower growth and survival metrics. Fish in the tapioca treatment had the lowest survival rate (60 ± 5%) and the highest FCR (1.32 ± 0.30), indicating suboptimal nutrient utilisation and possibly poorer floc quality. These findings are consistent with previous studies that demonstrated the efficacy of molasses or jaggery in enhancing microbial activity and promoting growth in aquaculture species such as shrimp and tilapia (Sakkaravarthi & Sankar, 2015; Serra et al., 2015; Silva et al., 2017; Kumar et al., 2017). Similarly,

Table 3. Growth performance, feed utilisation, and survival of *E. suratensis* reared under different carbon source treatments in biofloc systems

Parameters	Sugar	Tapioca Flour	Corn Flour	Wheat Bran	Jaggerry	F value	P value
Initial Length (cm)	4.18±0.15^{d}	4.3±0.08^{b}	4.2±0.07^{a}	4.2±0.08^{c}	4.1±0.23^{c}	4.697	0.22
Final Length (cm)	5.76±0.05	5.66±0.11	5.7±0.10	5.71±0.12	5.72±0.09	0.516	0.726
Initial Weight (g)	1.55±0.10	1.61±0.02	1.51±0.10	1.55±0.09	1.43±0.15	15.430	0.000
Final Weight (g)	4.7±0.1^{b}	4.1±0.11^{e}	4.2±0.2^{d}	4.4±0.1^{c}	4.7±0.24^{a}	16.442	0.000
Weight Gain (g)	3.15±0.05^{b}	2.52±0.13^{e}	2.7±0.1^{d}	2.86±0.16^{c}	3.29±0.09^{a}	16.856	0.000
Length Gain (cm)	1.57±0.09	1.3±0.13	1.41±0.09	1.45±0.08	1.62±0.20	0.415	0.794
SGR (%/day)	1.9±0.02^{ab}	1.67±0.08^{c}	1.8±0.08^{b}	1.86±0.07^{b}	2.06±0.03^{a}	15.731	0.000
FCR	1.08±0.17	1.32±0.3	1.25±0.28	1.13±0.15	0.9±0.05	1.680	0.230
Survival (%)	75 ± 5^{b}	60±5^{e}	65±10^{d}	76±7.6^{c}	86±3.6^{a}	203.597	0.000

Note: Values are mean ±SD of three replicates, and values with different superscript letters are significantly different at $p < 0.05$

Wang et al. (2016) reported improved performance in *L. vannamei* when a mixture of carbon sources (molasses, corn flour, wheat bran) was used. Jackqulinwino et al. (2024) also reported high growth performance of *Etroplus suratensis* in an in situ experiment using a jaggery-based biofloc system.

In contrast, the present study, using a single-source jaggery, found it more efficient, which supports the study by Elayaraja et al. (2020) on Nile tilapia (*Oreochromis niloticus*), which reported a higher survival rate and better growth performance. The digestibility and nutritional quality of the biofloc were markedly influenced by the type of carbon source used, as reported early by Susitharan et al. (2021). Biofloc quality is known to play a critical role in the nutrition of larval and juvenile fish, particularly when natural food sources are limited (Das et al., 2007). The relatively higher protein content and microbial biomass in the jaggery treatment contributed to enhanced growth and nutrient assimilation. Overall, the results underscore the importance of selecting an appropriate carbon source in biofloc technology. Jaggery emerged as the most effective option for improving biofloc quality and promoting the growth and survival of *E. suratensis* under controlled culture conditions.

3.4 Total Plate Count (TPC)

Heterotrophic bacteria play a key role in biofloc systems by converting organic carbon and inorganic nitrogen into microbial protein (Avnimelech, 1999; Chamberlain et al., 2001). However, conventional high-protein aquaculture diets typically have low C: N ratios (<10:1), which may hinder bacterial assimilation and lead to the accumulation of ammonia, nitrite, and nitrate (McIntosh, 2000). A C: N ratio of approximately 15:1 is considered ideal for optimal microbial activity (Chamberlain et al., 2001), and this ratio was maintained across all treatments.

Among treatments, treatment 5 (jaggery) showed the highest TPC count (Fig 1) and the highest average floc volume (9.6 ml/L), while the other treatments had significantly lower floc volumes. Despite similar CHN values among carbon sources, jaggery stimulated greater microbial biomass, likely due to its composition and rapid microbial utilisation.

3.5 Proximate Composition

3.5.1 Biofloc

The proximate composition of bioflocs varied significantly depending on the carbon source, as summarised in Table 4. The highest crude protein (37.40 ± 0.11%) and fat (4.16 ± 0.05%) content were observed in bioflocs derived from jaggery, followed by those generated using sugar and wheat bran. Crude fibre content was also highest in jaggery-based floc (3.52 ± 0.03%), suggesting a more complex microbial and particulate matrix. These results support earlier findings that the nutritional quality of biofloc is influenced by the type and complexity of the added carbon source (Azim & Little, 2008; Kuhn et al., 2009).

The higher protein and lipid content in jaggery-derived flocs likely contributed to the improved growth and feed conversion observed in that treatment, as reported by Anitha et al. (2025a). In contrast, flocs produced from corn and tapioca flour had lower nutritional value, potentially leading to reduced digestibility and poorer fish performance.

3.5.2 Fish

The proximate composition of fish muscle samples fed with biofloc diets derived from various carbon sources is summarised in Table 5. All fish samples were analysed on a dry matter basis. Fish from the jaggery (JG) treatment group showed the highest crude protein content (52.97 ± 0.02%), followed by sugar (SG: 49.05 ± 0.15%), wheat bran (WB: 46.39 ± 0.14%), corn flour (CF: 45.02 ± 0.05%), and tapioca flour (TF: 44.71 ± 0.22%). This indicates that the JG treatment enhanced protein assimilation, likely due to improved microbial floc digestibility and a more favourable nutritional profile. The superior performance of JG is consistent with previous findings that molasses-based carbon sources support better biofloc quality and nutrient retention in fish (Sakkaravarthi & Sankar, 2015; Silva et al., 2017; Anitha et al., 2025b).

In terms of crude fat, jaggery-fed fish again recorded the highest values (8.8 ± 0.22%), whereas TF-fed fish had the lowest (7.21 ± 0.2%). Higher lipid content in fish may reflect improved energy utilisation and a more balanced microbial community, as provided by jaggery-based bioflocs. Crude

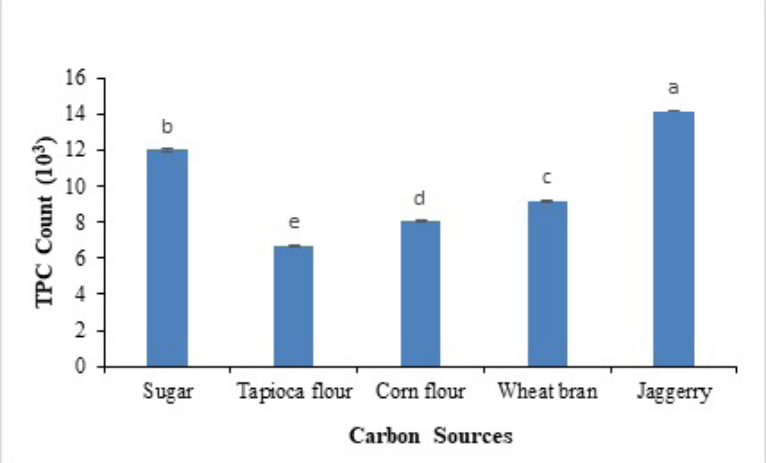


Fig. 1. Total Plate Count (TPC)

Table 4. Proximate Composition of Biofloc Produced Using Different Carbon Sources (Dry Matter Basis)

Nutrients	Sugar	Tapioca Flour	Corn Flour	Wheat Bran	Jaggery	F value	p value
Crude Protein(%)	35.07±0.18^{b}	33.19±0.26^{d}	33.20±0.12^{d}	34.07±0.32^{c}	37.40±0.11^{a}	193.602	0.000
Crude Fat (%)	3.91±0.0^{b}	3.14±0.01^{d}	3.09±0.03^{d}	3.58±0.07^{c}	4.16±0.05^{a}	182.875	0.000
Crude Fibre (%)	2.93±0.03^{b}	2.76±0.01^{d}	2.76±0.02^{d}	2.84±0.02^{c}	3.52±0.03^{a}	523.954	0.000
Crude Ash (%)	14.89±0.03^{b}	13.14±0.02^{d}	13.18±0.02^{d}	13.34±0.03^{c}	16.83±0.01^{a}	10811.463	0.000

Note: Values are mean ±SD of three replicates, and values with different superscript letters are significantly different at $p < 0.05$

Table 5. Proximate Composition of Fish Fed with Different Carbon Source-Derived Bioflocs

Nutrients	Sugar	Tapioca Flour	Corn Flour	Wheat Bran	Jaggerry	F value	p value
Crude Protein (%)	49.05±0.15^{b}	44.71±0.22^{e}	45.02±0.05^{d}	46.39±0.14^{c}	52.97±0.02^{a}	1898.06	0.000
Crude Fat (%)	8.03±0.08^{b}	7.21±0.2^{e}	7.6±0.23^{d}	7.7±0.16^{c}	8.8±0.22^{a}	31.631	0.000
Crude Fibre (%)	0.05±0.01	0.02±0.01	0.02±0.01	0.02±0.01	0.03±0.02	2.800	0.085
Crude Ash (%)	9.58±0.04^{ab}	9.24±0.06^{ab}	9.65±0.31^{ab}	8.88±0.2^{b}	9.99±0.7^{a}	3.546	0.048

Note: Values are mean ±SD of three replicates, and values with different superscript letters are significantly different at $p < 0.05$

fibre content remained low across all treatments, ranging from 0.02 ± 0.01% to 0.05 ± 0.01%, which is typical for fish muscle tissue and indicates efficient digestion of biofloc materials. Overall, these results indicate that jaggery is the most effective carbon source for promoting muscle development and nutrient deposition in *E. suratensis* under biofloc systems. The enhanced nutritional composition in JG-fed fish supports earlier findings that molasses-type carbon sources improve microbial activity and protein retention (Singh, 2001; Serra et al., 2015; Kumar et al., 2017).

4. Conclusion

This study clearly demonstrates that the type of carbon source significantly influences biofloc development, water quality, microbial dynamics, and fish growth performance in biofloc-based aquaculture systems. Among the five tested carbon sources, jaggery emerged as the most effective in promoting optimal biofloc formation, enhancing microbial activity, and improving water quality. Pearlspot cultured under jaggery-based BFT conditions exhibited the highest growth, survival, and muscle nutrient content, including crude protein and fat. The superior performance of jaggery can be attributed to its rapid biodegradability, nutrient-rich composition, and its ability to support dense microbial floc communities. Given its local availability, cost-effectiveness, and proven efficacy, jaggery represents a promising carbon source for scalable, eco-friendly aquaculture of *E. suratensis* and potentially other species suited for BFT systems.

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