Brewers's spent grains as an economical alternative to fishmeal in goldfish (*Carassius auratus*) diet

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Abstract

Cost-effective and nutritionally balanced diet is fundamental for successful ornamental fish farming. This study aimed to investigate replacement level of fishmeal with brewer's spent grain (BSG) in the diet of Carassius auratus to reduce production cost. A control diet was formulated to contain 40% crude protein and 21 kJ g^{-1} of gross energy. Three experimental diets were formulated by replacing 10%, 20%, and 30% of fishmeal in the control diet with BSG. Using a completely randomized design, 120 fish (1.13±0.06 g) were assigned to 12 concrete-glass tanks (70×30×30 cm) at the rate of ten per aquarium, representing three tanks for each diet. The fish were fed twice a day (08:00 am and 03:00 pm) until satiation for six weeks. Water quality parameters were measured daily and maintained within the standard range. At the end of the experiment, fish survival was 95%. Length and weight gains of fish fed the experimental diets were higher ($p<0.05$) than those fed the control diet. Polynomial regression curves delineated the maximum length gain at 18.5% replacement of fishmeal with BSG while the maximum weight gain was at 9.6%. However, daily feed intake and feed conversion ratio did not differ ($p>0.05$) among the dietary groups. Condition factor of fish was significantly higher ($p<0.05$) in the treated groups. The estimated cost per kilogram feed showed a decreasing trend towards increasing level of BSG in the diet. In conclusion, 18.5% dietary BSG with the expense of fishmeal improved the growth of goldfish and reduced the feed cost. Further studies are recommended to investigate nutrient utilization and immunity of fish.

Keywords: Low-cost feed, Calico Ryukin, Ornamental fish, SGR

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Introduction

The aquaculture industry is highly dependent on commercial fish feed, which determines the overall productivity of the fish farm. Feed cost is the biggest financial obstacle in aquaculture, particularly when using expensive ingredients like fish oil and fishmeal (Opiyo *et al*., 2024; Roos, 2025). Although fishmeal production has declined due to overfishing and the depletion of marine resources (Soliman *et al*., 2017; Liu *et al*., 2020), it has been the major protein source in aquafeed because of its high digestibility and rich nutrient content (Cho and Kim, 2011). There has been growing interest in alternative feed ingredients to partially replace high-cost fishmeal in fish feeds (Perera and Bhujel, 2022; Dan *et al*., 2023). Cost-effective practical diets formulated using locally available grains, plant-based proteins, and industrial by-products seem to be an upward trend in aquaculture (Li *et al*., 2021; Opiyo *et al*., 2024). Brewer's spent grain (BSG), a by-product of the brewing industry, has gained interest as a potential protein source to replace the plant- or animal-based products and sustain fish farming (Ikram *et al*., 2017; Estévez *et al*., 2021). In carp *Cirrhinus reba*, BSG-supplemented diets enhance the carcass protein and long-chain polyunsaturated fatty acid contents, while reducing feed costs by more than 50% compared to conventional diets (Chattaraj *et al*., 2024a). However, dietary supplementation of BSG reduces the growth in Nile tilapia *Oreochromis niloticus* and channel catfish *Ictalurus punctatus* (Tidwell *et al*., 2021). Meanwhile, Estévez *et al*. (2022) observed no differences in muscle composition and growth of rainbow trout *Oncorhynchus mykiss* fed dietary BSG. Accordingly, the research has consistently shown that the efficiency of utilizing dietary BSG widely varies among farmed fish species.

Goldfish *Carassius auratus,* is a globally popular freshwater ornamental fish that belongs to the family Cyprinidae (Massey *et al*., 2025). In 2023, the global trade of goldfish was USD 674 million and is anticipated to increase at 5.7% per year from 2024 to 2032 (Patel, 2024). Nevertheless, goldfish aquaculture highly depends on fishmeal-based commercial diets, and does not make appreciable profit forever (Choden *et al*., 2024). Hence, several studies have focused on its nutrition and practical feed formulations. Souto *et al*. (2013) found that goldfish require around 30 to 40% protein in their diet. The feasibility of replacing dietary fishmeal with brewer's yeast (Gümüş *et al*., 2016), fermented soybean meal (da Cunha *et al*., 2022), and sunflower meal (Bilen and Bilen, 2013) has been evaluated. However, there is no established literature on the utilization of BSG by the goldfish, though the potential of its dietary supplementation could be promising (Chattaraj *et al*., 2024c). Hence, the objective of the present study was to determine the optimal level of dietary fishmeal replacement with BSG based on the

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growth performance of *Carassius auratus* var. Calico Ryukin to reduce production cost.

Materials and methods

Experimental diet

A control diet without BSG was formulated to contain 40% crude protein and 21 kJ g^{-1} of gross energy using fishmeal and soybean meal as the protein sources, along with corn, wheat, rice bran, and soybean oil. Then, three experimental diets were formulated to replace 10, 20, and 30% of fishmeal in the control diet with BSG (Table 1). Fresh BSG was obtained from Lion Brewery (Ceylon) PLC, which was oven-dried, ground, and sieved to produce fine particles smaller than 50 µm. The pre-weighed ingredients were mixed well. Once the ingredients were dry, oil was added and mixed carefully. A small amount of warm water was added and mixed until a paste-like consistency was achieved. A squeezer was used to extrude the dough, and it was steam-cooked. Pellets were initially air-dried before being oven-dried at 60 °C until their weight was stable. The dried pellets were weighed, individually packaged, and stored in a freezer in airtight polyethene bags with clear labels. Proximate analysis was done according to standard methods (AOAC, 1997).

Table 1: Formula and proximate composition (% as fed basis) of the experimental diets.

Ingredient (%)	Control	Level of fishmeal replacement		
		10%	20%	30%
Corn	18.0	3.5	3.9	0.1
Wheat	2.5	17.3	11.0	3.9
Rice bran	9.0	1.7	0.5	0.5
Soybean meal	39.5	39.5	40.0	41.5
Brewer's spent grain	0	8.1	16.2	26.2
Fishmeal	26.0	23.4	20.8	18.2
Soybean oil	4.0	5.5	6.5	8.6
Vitamin & mineral mixture	1.0	1.0	1.0	1.0
Proximate composition				
Moisture	11.5	6.5	3.0	9.0
Crude protein	40.6	39.9	39.1	38.0
Crude lipid	10.5	11.1	9.9	7.4
Crude fiber	2.0	1.8	2.0	2.3
Crude ash	7.3	6.4	7.7	5.0
Nitrogen free extract	28.1	34.3	38.3	38.3
Gross energy (kJ g^{-1})	20.9	21.1	20.6	20.4
P:E (mg protein kJ^{-1} of energy)	19.4	18.9	19.0	18.6

Experimental design

The experiment was conducted in twelve rectangular concrete-glass tanks (70×30×30 cm) filled with de-chlorinated water up to two-thirds of their capacity. One hundred and twenty mixed-sex *Carassius auratus* (Calico Ryukin variety) were procured from the Oasis Ornamental Fish Farm Breeding Center, Polonnaruwa, Sri Lanka. After acclimatizing for three days, the fish with an average weight of 1.13 ± 0.06 g

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were randomly introduced into twelve tanks at the rate of ten per aquarium. The experiment was conducted with four treatments and three replicates in a Complete Randomized Design (CRD) for six weeks.

Experimental setup and sampling

Fish were fed different experimental diets twice a day (08:00 am and 03:00 pm), and daily feed consumption was recorded throughout the experimental period. Feed remnants were collected 30 minutes after each feeding over a 6-week study to determine total feed intake. Water quality parameters were measured daily and maintained them within the standard range as follows: temperature, 26.6–27.0 ℃; pH, 7.1–7.4; dissolved oxygen, >3.0 mg/L and total ammonium nitrogen, 0.1–0.3 mg/L.

The initial body weight and body length were measured at the start of the feeding trial using an electronic balance and a measuring board, respectively, and were then recorded every week after that. Fish were anaesthetized with Ocean-free arowana stabilizer (1 mL/L of water) throughout every single sampling. At the end of the trial, weight gain (WG), length gain (LG), daily feed intake (DFI), specific growth rate (SGR), condition factor (CF), and feed conversion ratio (FCR) of fish were measured as described by Goddard (1996):

Weight gain (WG)

$$\text{Weight gain}(\%) = \frac{\text{Final body weight} - \text{Initial body weight}}{\text{Initial body weight}} \times 100$$

Percentage length gain (LG)

$$\text{Length gain}(\%) = \frac{\text{Final body legnth} - \text{Initial body length}}{\text{Initial body length}} \times 100$$

Specific growth rate (SGR)

$$\text{SGR} = \frac{(\text{Wt2}) - (\text{Wt1})}{\text{t2} - \text{t1}} \times 100\%$$

Where, W_{t1}: Weight at time t1 (initial weight) (g) t_1; Initial time, W_{t2}: Weight at time t2 (final weight) (g) t_2; Final time

Condition factor

$$\text{CF} = \frac{Body\ weight}{(Total\ length)^3} \times 100$$

Where, W =Weight of fish (g); L=Length of fish (cm)

Feed conversion ratio (FCR)

$$\text{FCR} = \frac{\text{Feed intake}}{\text{Weight gain of fish}} \times 100$$

Survival

$$\text{Survival} = \frac{\text{Number of fish at the end of the experiment}}{\text{Number of fish stock at the beginning}} \times 100\ \%$$

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Cost Analysis

For each of the experimental and control diets, a cost analysis was conducted using the current market pricing of the goods used. The cost per kilogram was estimated for this analysis.

Statistical analysis

The Statistical Analysis System (SAS) version 9.4 was used to tabulate the data gathered from lab studies and perform an Analysis of Variance (ANOVA). Once the main effects were shown to be significant at $p<0.05$, substantially different treatment means were separated using Duncan's Multiple Range Test (DMRT). The optimal inclusion level of BSG was estimated using third-order polynomial regression analysis.

Results

Growth performance and feed utilization

Results revealed a 95% survival in fish fed both the control and experimental diets. Growth performance and feed utilization metrics of goldfish juveniles fed with different levels of dietary BSG for 42 days are shown in Table 2. The final total length and the length gain of fish fed the experimental diets were significantly higher ($p<0.05$) than those fed the control diet. The highest total length and the length gain were observed in fish fed 20% dietary replacement of fishmeal with BSG. There was no significant difference in the length measurements of fish fed 10% and 30% replacement of fishmeal with BSG. Third-order polynomial regression curve delineated the maximum length gain of goldfish fry at 18.5% dietary replacement of fishmeal with BSG (Fig. 1).

Table 2: Growth performance and feed utilization of goldfish juveniles fed BSG diets for 42 days.

Parameters	Control	Level of fishmeal replacement by BSG (%)		
		10	20	30
Initial length (cm)	3.07 ± 0.05^{a}	3.10 ± 0.07^{a}	3.17 ± 0.10^{a}	3.44 ± 0.01^{a}
Initial weight (g)	1.16 ± 0.03^{a}	1.06 ± 0.03^{a}	1.16 ± 0.09^{a}	1.13 ± 0.03^{a}
Final length (cm)	5.52 ± 0.06^{c}	5.94 ± 0.05^{b}	6.27 ± 0.13^{a}	6.01 ± 0.00^{b}
Length gain (%)	79.8 ± 0.9^{c}	91.7 ± 2.7^{b}	97.8 ± 2.1^{a}	74.7 ± 0.5^{d}
Final weight (g)	4.18 ± 0.26^{a}	4.26 ± 0.22^{a}	4.40 ± 0.38^{a}	4.21 ± 0.21^{a}
Weight gain (%)	260.1 ± 13.1^{c}	301.7 ± 9.4^{a}	279.1 ± 3.5^{b}	272.4 ± 8.7^{bc}
SGR (%/d)	3.2 ± 0.1^{c}	3.5 ± 0.1^{a}	3.3 ± 0.0^{b}	3.3 ± 0.1^{bc}
DFI (% BW/d)	7.1 ± 0.9^{a}	6.8 ± 0.9^{a}	7.1 ± 0.9^{a}	6.7 ± 0.7^{a}
FCR	2.5 ± 0.3^{a}	2.3 ± 0.2^{a}	2.4 ± 0.3^{a}	2.3 ± 0.2^{a}
Condition factor	2.5 ± 0.1^{a}	2.0 ± 0.1^{b}	1.8 ± 0.0^{c}	1.9 ± 0.1^{b}

Values are means of three replicates ± Standard deviation. Means followed by the same letter in each row do not differ significantly at $p<0.05$ based on DMRT.

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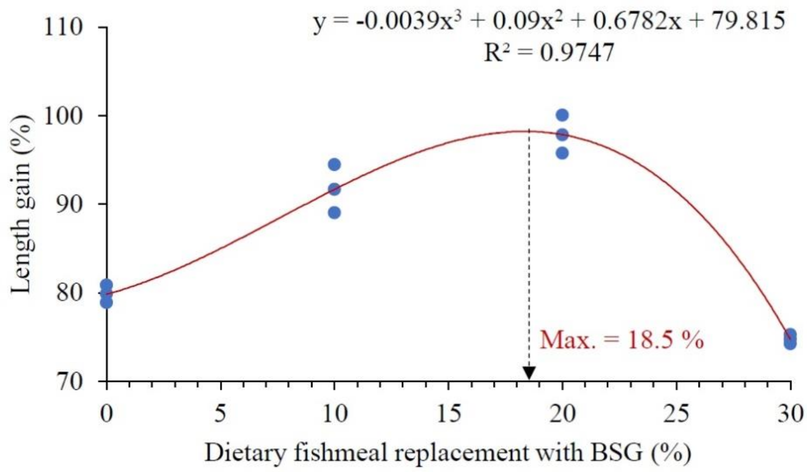

Figure 1: Relationship between dietary replacement level of fishmeal with BSG and the length gain of goldfish fry.

The goldfish juveniles fed the control and experimental diets did not differ (p>0.05) in the final weight. However, weight gain and specific growth rate were significantly higher (p<0.05) in fish fed diets with 10% and 20% replacement of fishmeal compared to those fed the control diet. The highest weight gain and specific growth rate were observed in fish fed diet with 10% fishmeal replacement. Third-order polynomial regression curve delineated the maximum specific growth rate of goldfish fry at 9.6% dietary replacement of fishmeal with BSG (Fig. 2).

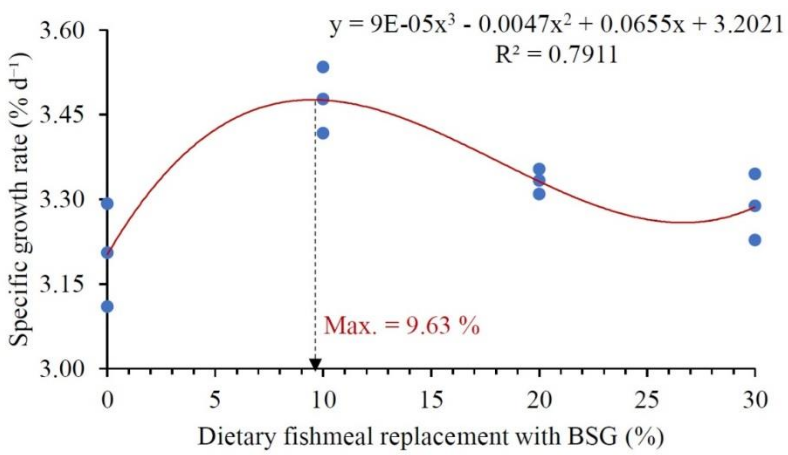

Figure 2: Relationship between dietary replacement level of fishmeal with BSG and the specific growth rate of goldfish fry.

Besides, the daily feed intake (6.7–7.1 % BW/d) and feed conversion ratio (2.3–2.5) did not differ (p>0.05) among the treatment groups. The condition factor of fish was significantly lower (p<0.05) in the treated groups compared to the control group. The lowest condition factor was in the fish fed diet with 20% fishmeal replacement. Second-order polynomial regression curve delineated the minimum condition factor of goldfish fry at 21.5% dietary replacement of fishmeal with BSG (Fig. 3).

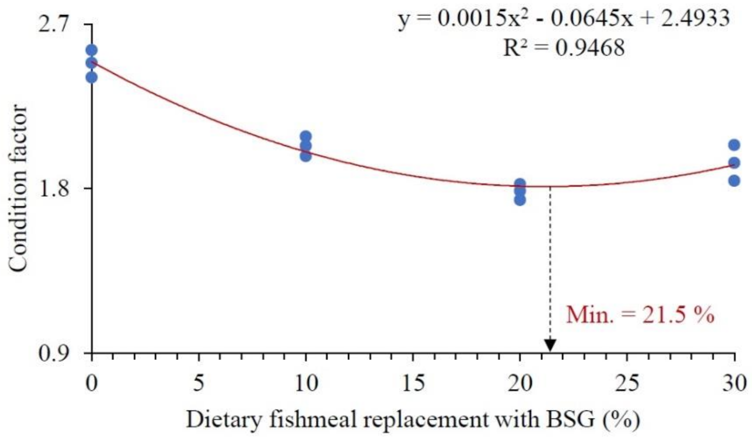

Figure 3: Relationship between dietary replacement level of fishmeal with BSG and the condition factor of goldfish fry.

Cost analysis

The estimated costs to formulate the control and experimental diets based on the local market price are presented in Table 3. The average feed cost showed a decreasing trend with the increasing levels of dietary fishmeal replacement. There were 9.7%, 19%, and 33% reductions in the feed cost when the dietary fishmeal was replaced by 10%, 20%, 30%, respectively.

Table 3: Estimated unit costs (LKR per kilogram) for the diets formulated with the inclusion of BSG.

Feed ingredient	Ingredient cost (LKR kg^{-1})	Feed cost (LKR kg^{-1})			
		Control	10%	20%	30%
Corn	400.0	72.00	14.00	15.70	0.40
Wheat	305.2	7.63	52.23	33.61	11.76
Rice bran	100.0	9.00	1.69	0.50	0.50
Soybean meal	110.0	43.45	43.45	44.00	45.65
Brewer's spent grain	40.1	0.00	3.25	6.50	10.50
Fishmeal	600.0	156.00	140.40	124.80	109.20
Soybean oil	185.0	7.40	10.19	12.03	15.91
Vitamin & mineral mixture	1 200.0	12.00	12.00	12.00	12.00
Feed cost (LKR kg^{-1})		307.48	277.71	249.16	205.90

Discussion

The impact of the feed cost, especially in ornamental fish farming, is a crucial factor that plays a major role in the overall productivity of the aquaculture industry. According to Kumar *et al.* (2017), feed cost often accounts for over 50% of the total production cost, which means any fluctuations in feed cost may cause a severe impact on the economic stability of the aquaculture industry. Meanwhile, ornamental fish farming highly depends on quality feeds to maintain the health and development of the fish, which in turn influences the visual attractiveness and market value of

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the fish. In this context, the current study focused on evaluating the dietary BSG, a locally available by-product of brewing industries, on the growth performance of *Carassius auratus* var. Calico Ryukin. Previously, Ikram *et al*. (2017) suggested the use of BSG as a potential source of essential amino acids in animal feeds, and later it has been successfully tested in aquafeeds (Jayant *et al*., 2018; Nazeer *et al*., 2022; Chattaraj *et al*., 2024b).

The results of the present study revealed high survival rates and equal DFI and FCR across all dietary treatments. It ensured that the palatability of the control and experimental diets was acceptable to *C. auratus* and not restricted by the availability of dietary essential amino acids that are indispensable for body weight gain (Teoh and Wong, 2021; Nazeer *et al*., 2022). Generally, either deficiency or oversupply of essential amino acids limits the fish growth due to poor palatability and associated low feed intake (Xing *et al*., 2024). However, the present study showed that the dietary replacement of 9.6–18.5% fishmeal with BSG enhanced weight and length gains of *C. auratus*. Irrespective of a non-significant change in the DFI and FCR, the optimum level of BSG improved the fish growth might be due to the efficient utilization of dietary protein and energy. The feeds with 10–20 % fishmeal replacement supplied 18.9–19.0 mg protein per kJ of gross energy, whereas the control and the 30% fishmeal replacement diets supplied slightly higher and lower protein-to-energy ratios, respectively. Studies of Kaushik (1995) confirm this norm that increasing the dietary protein-to-energy ratio beyond 19 mg of digestible protein per kJ digestible energy does not improve the weight gain in carps. However, one of the studies in goldfish recommends 28–30 mg protein per kJ of digestible energy for a maximum weight gain in *C. auratus,* with an average initial weight of 1.78 g (Souto *et al*., 2013). However, there is no generalized evidence for the relationship between protein requirement and body size of the fish (Xing *et al*., 2024). Similar to the current study, Gümüş *et al*. (2016) reported growth improvement in *C. auratus* fed 35% dietary replacement of fishmeal with brewers' yeast. According to Estévez *et al*. (2021), gilthead seabream (*Sparus aurata*) equally performs when fed with either 30% brewers' spent yeast or 15% BSG. These studies imply that the utilization of dietary BSG by the fish is lower than brewers' spent yeast. Accordingly, a maximum of 20% fishmeal replacement with BSG in the goldfish diet agrees with the findings of Gümüş *et al*. (2016). In contrast, Nile tilapia (*Oreochromis niloticus*) and channel catfish (*Ictalurus punctatus*) show retarded growth when fed BSG with exogenous enzymes (Tidwell *et al*., 2021).

The condition factor is an indicator of fish welfare (Engebretsen *et al*., 2024). The factor increases when the fish are healthier due to the deposition of excess energy reserves, and declines when they are lighter (Morado *et al*., 2017). Even though the condition factor of *C. auratus*

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in the present study was greater than one across all the dietary groups, indicating a rich welfare status, it decreased towards increasing dietary BSG level until 21.5%. Hence, it is advantageous to limit at 20% BSG with the expense of fishmeal to secure a better welfare. This result is consistent with those of Gümüş *et al*. (2016), who reported a decreasing trend of condition factor in goldfish fed increasing levels of dietary brewer's yeast. Study of Tidwell *et al*. (2021) indicated that the growth and condition factor of Nile tilapia and channel catfish simultaneously decrease when fed with increasing levels of dietary BSG.

Replacement of fishmeal with BSG caused substantial differences in feed costs. The control diet was the most expensive one due to absence of BSG instead of fishmeal, which was the most expensive feedstuff in the diet (Opiyo *et al*., 2024; Roos, 2025). According to the fish growth in the present study, the estimated total feed cost per kilogram of fish showed a linear decrease with increasing replacement of BSG. These results are in line with those of previous studies in stiped catfish fed dietary BSG (Jayant *et al*., 2018).

Conclusion

In conclusion, this study is the first to provide invaluable insight into the potential of BGS as an alternative to fishmeal in the diet of *C. auratus* kept in outdoor tanks. Key findings of this study centre on two main aspects. First, the expensive fishmeal in the goldfish diet could be optimally replaced by BSG at 18.5% without affecting the growth. Second, use of BSG could significantly reduce the feed cost. Accordingly, this research contributes for low-cost production of practical feed for aquarium industry. However, it is recommended to further investigate the effects of BSG on nutrient utilization and immunity of *C. auratus* to sustain the low-cost production.

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