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Fermented brewery spent grain as a sustainable protein source for guppy (*Poecilia reticulata*): A review of evidence on growth, coloration and fry production

Jayasingha W.D.C.K.[1*]; Chathurangi K.D.G.[2]

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Abstract

The guppy (*Poecilia reticulata*) is one of the most widely cultured freshwater ornamental fish species, and its commercial value is largely determined by three nutrition-sensitive traits: growth performance, male body coloration, and female reproductive output. Conventional ornamental fish feeds rely heavily on fishmeal and other protein sources of marine or terrestrial origin, whose availability, cost, and environmental footprint have increased interest in alternative feed ingredients. Brewery spent grain (BSG), the major solid by-product of the brewing industry, is generated in substantial quantities and contains approximately 20% protein and a high proportion of dietary fibre on a dry-matter basis. Despite its nutritional potential, its high fibre content and relatively limited nutrient availability present challenges to its direct inclusion in aquafeeds. Evidence from studies on food fish species suggests that solid-state fermentation and enzymatic pre-treatment can improve the nutritional quality, digestibility, and feed utilization of BSG-containing diets. Furthermore, partial replacement of conventional dietary protein sources with processed BSG has supported growth performance comparable to that of control diets at moderate inclusion or replacement levels in some species. However, the applicability of these findings to ornamental fish, particularly guppies, remains largely unexplored. To our knowledge, no peer-reviewed study has directly evaluated fermented BSG as a dietary ingredient in guppy nutrition. Accordingly, this review synthesizes available evidence from BSG-based aquafeed research, guppy nutritional requirements, and ornamental fish pigmentation and reproductive physiology. It aims to (i) develop testable hypotheses regarding the potential effects of fermented BSG on growth performance, coloration, and fry production; (ii) identify major nutritional and physiological constraints, particularly dietary fibre, antinutritional factors, and carotenoid availability; and (iii) propose a three-phase experimental framework for evaluating its suitability in guppy diets. This review provides a literature-based synthesis and research framework rather than reporting original experimental findings.

Keywords: *Poecilia reticulata*; brewery spent grain; solid-state fermentation; ornamental fish nutrition; carotenoids; fecundity; sustainable aquafeeds.

1-Department of Aquaculture and Seafood Technology, Faculty of Fisheries and Ocean Sciences, Ocean University, Sri Lanka

2-Department of International Business, Faculty of Management and Finance, University of Colombo, Sri Lanka

[*]Corresponding author's Email: chathuocean98728@gmail.com

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Introduction

The aquaculture of ornamental species is a low-volume, high-value enterprise that sells products based upon their visual appeal and vitality rather than on their potential for food production. Because of its hardiness, ability to produce live offspring (livebearer), and availability in an extremely wide array of color varieties, the guppy is a major player in this market. From a producer perspective, the amount of money made is dependent upon the time it takes for juvenile fish to attain commercial size; the intensity of the coloration displayed by male fish; and the number of fry produced by females in each brood. Diets affect all three aspects of production and represent the greatest recurring cost for most producers. The production of aqua feed has relied heavily on marine resources over the years; however, a retrospective analysis of twenty years of aquaculture indicates that the reliance on marine sources continues to exist, although there is a larger use of terrestrial resources (Naylor *et al*., 2021). Plant based alternative sources of protein can provide some solutions to reducing reliance on marine resources but do have some limitations such as the presence of ant nutritional factors that can negatively affect the ability of fish to utilize nutrients from their diet (Francis *et al*., 2001).Fermentation is one of the processing strategies proposed to overcome these limitations and to raise the value of plant-based feed materials (Dawood and Koshio, 2020).Brewery spent grain (BSG) is the solid residue left after mashing barley malt and other cereals. It is the major brewing by-product, representing about 85% of the total by-products generated, and is available in large quantities throughout the year. Its composition is approximately 20% protein and 70% fibre on a dry basis, the latter made up of cellulose, non-cellulosic polysaccharides (mainly arabinoxylans) and lignin (Mussatto *et al*., 2006). It has been reviewed extensively as a food and health ingredient (Lynch *et al*., 2016), and a recent review specifically addresses its use as a partial replacement for fishmeal and soybean meal in fish feeds within a circular-economy framework. The same review reports crude protein contents of roughly 15–27% on a dry-matter basis and an essential amino acid profile that is relatively balanced for its protein level, but also notes that high fibre, lignin and antinutritional factors can reduce digestibility and palatability (Geremia *et al*., 2026).

This paper asks three questions about fermented BSG in guppy diets: what does the existing evidence suggest about growth performance; what is known about how the diet could influence body coloration; and how might the diet affect fry production? Because experimental work on this exact combination appears not to have been published, the paper synthesises evidence from related studies and sets out a design to test the predictions. As with the related reviews on fisheries and aquaculture issues in the Sri Lankan context, it synthesises

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existing published evidence rather than presenting new experimental data.

Brewery spent grain as a fish feed ingredient

Composition and limitations of untreated spent grain

The nutritional profile of BSG is dominated by two features: a moderate protein fraction and a very large fibre fraction (Mussatto *et al*., 2006; Lynch *et al*., 2016). In fish, fibre of this kind is poorly digested, and the review of Geremia *et al*. (2026) summarises that high inclusion of untreated BSG can lower feed intake, digestibility and growth. In Nile tilapia, one study reviewed there found reduced growth at 27% and 55% BSG inclusion, and in whiteleg shrimp performance declined when fishmeal replacement reached about 70% (Geremia *et al*., 2026). Guppies are small omnivorous livebearers with a short digestive tract, so any fibre-related penalty is likely to be at least as pronounced as in the species studied so far; this inference has not been tested directly.

Effect of fermentation and enzymatic pretreatment

Processing appears to alleviate part of the limitation. In the review by Geremia *et al*. (2026), solid-state fermented and hydrolysed BSG generally improved feed efficiency and digestibility, and 10% fermented BSG improved growth and feed efficiency in meagre and European seabass. A dedicated study of solid-fermented BSG in European seabass examined growth, metabolism and oxidative status (Estevão-Rodrigues *et al*., 2025); we cite it as evidence that the approach has been evaluated in fish, but do not report its quantitative results here because they were not available to us from the source page consulted. Using a different route, a carbohydrase-rich extract produced by solid-state fermentation of BSG with *Aspergillus ibericus* was added at 0.4% to seabass diets and increased the digestibility of dry matter, starch, cellulose, glucans and energy, although protein digestibility was unchanged. The same study reported that endogenous fish enzymes reduced the extract's activity in vitro, and the authors suggested protecting the extract, for example by coating (Fernandes *et al*., 2021). Two points follow for guppy feeds. First, the mechanism most strongly supported by the evidence is improved energy and carbohydrate digestibility, not improved protein digestibility, so fermented BSG is likely to be most useful as a partial protein and energy contributor rather than as a wholesale replacement for animal protein. Second, evidence from every study above comes from food-fish species at far larger body size than guppy juveniles, so extrapolation requires caution (Table 1). The conceptual framework linking fermented BSG to the outcomes considered in this paper is summarised in Figure 1.

Guppy protein nutrition, growth and fry production

Dietary protein level has long been recognised as a determinant of reproductive output in the guppy: a study of three protein levels examined their effect on fecundity in this species (Dahlgren, 1980).

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Table 1: Summary of evidence on brewery spent grain (BSG) in fish feeds and its relevance to guppy nutrition.

Aspect	Evidence in fish (non-guppy)	Source	Implication for guppy
Composition	~20% protein, ~70% fibre (dry basis); BSG ≈ 85% of brewery by-products	Mussatto *et al*. (2006)	Moderate protein; fibre limits inclusion
Inclusion limits	Comparable growth up to ~50% replacement of conventional protein; declines beyond; reduced tilapia growth at 27–55% BSG	Geremia *et al.* (2026)	Test low inclusion (5–20%) first
Fermented / hydrolysed BSG	Improved feed efficiency and digestibility; 10% fermented BSG improved growth in meagre and seabass	Geremia *et al.* (2026)	Prefer fermented over raw BSG
Enzyme extract from BSG	0.4% extract raised digestibility of dry matter, starch, cellulose, glucans, energy; protein unchanged	Fernandes *et al.* (2021)	Benefit likely via energy/carbohydrate use
Solid-fermented BSG in seabass	Growth, metabolism and oxidative status evaluated	Estevão-Rodrigues *et al*. (2025)	Supports feasibility; results not summarized here
Antinutritional factors	Plant ingredients contain antinutrients that reduce nutrient utilization	Francis *et al*. (2001)	Fermentation may lower ANF load

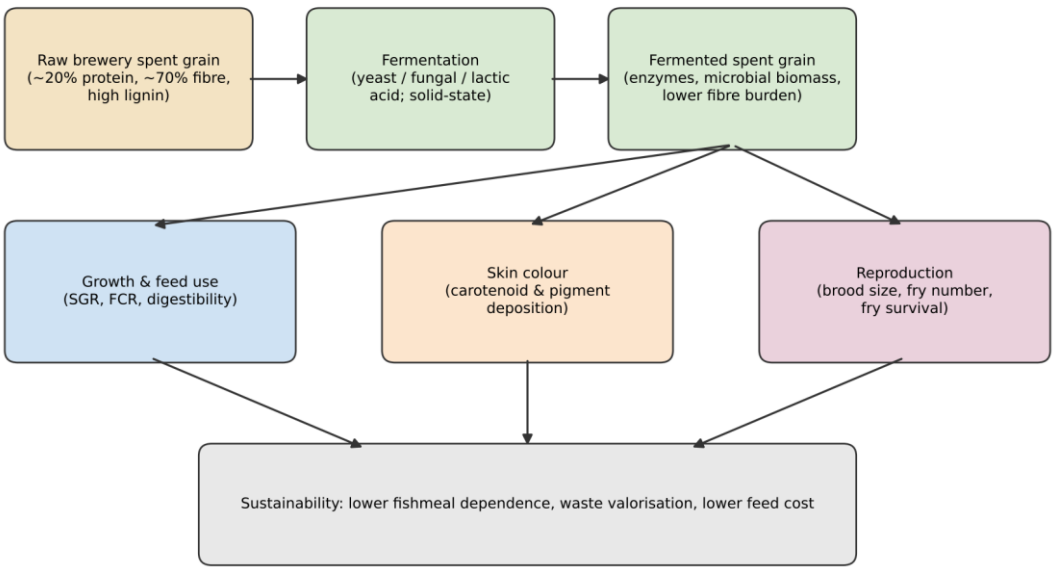

Figure 1: Conceptual framework: fermentation of brewery spent grain and its hypothesized links to growth, coloration and reproduction in guppies, and to the sustainability of ornamental feeds.

Because the livebearing guppy provisions embryos during gestation, brood size and fry quality are expected to reflect the nutritional state of the female, including protein and energy intake. A fermented BSG diet could affect fry production through three routes: the protein and amino acid supply it provides relative to the control diet, its effect on female body condition

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via energy digestibility, and any change in palatability that alters total intake. The main risk for reproduction is the same as for growth: if a high-fibre ingredient dilutes digestible energy or lowers intake, females may produce smaller broods or smaller fry. The sensible prediction, in line with the inclusion limits above, is therefore that low inclusion levels of fermented BSG should maintain, and not improve, brood size relative to a standard diet, while high inclusion levels risk reducing it. Because brood size in guppies also depends strongly on female size and age, any trial must standardise or covary these factors, and report fry numbers per brood, fry survival at defined ages, and fry weight at birth.

Body coloration: Carotenoid supply and pigment expression

In guppies fed 0, 5, 10 or 15% spirulina powder, skin redness (a*) increased from 59.05 in the control to 91.05 at 15%, final weight rose from 0.60 g to 0.78 g, specific growth rate from 0.74% to 0.86%, and feed conversion ratio fell from 3.28 to 2.91 (Bisht *et al*., 2023; Table 2, Fig. 2).

Table 2: Benchmark data from a guppy feeding trial with spirulina powder (Bisht *et al*., 2023).

Spirulina inclusion	Skin redness (a*)	Skin yellowness (b*)	Final weight (g)	SGR (%/day)	FCR
0% (control)	59.05	15.23	0.60	0.74	3.28
5%	69.68	16.25	–	–	–
10%	76.48	16.98	–	–	–
15%	91.05	17.38	0.78	0.86	2.91

available to us (–, not extracted). a*, skin redness; b*, skin yellowness; SGR, specific growth rate; FCR, feed conversion ratio.

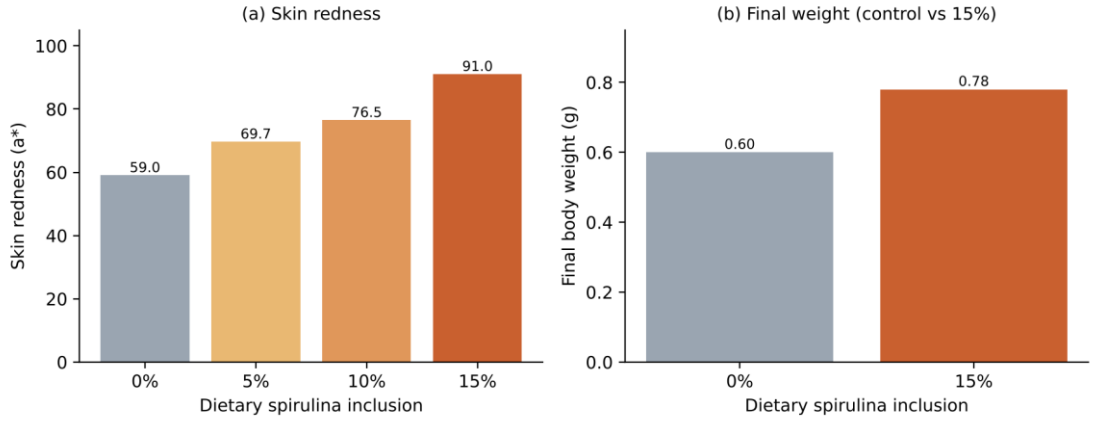

Figure 2: Benchmark effects of a carotenoid-rich ingredient (spirulina) on guppy skin redness and final weight, redrawn from the values reported by Bisht et al. (2023).

The figures above are provided merely as a point of reference; however, please note that there are many contradictions in the original article such as the duration of the trial being stated as both 60 days (in the abstract) and 90 days (in the methods) and conflicting reports regarding whether there were

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statistically significant differences in survival rates between groups (Bisht *et al*., 2023). Therefore, caution should be used when interpreting these findings. Additionally, this study demonstrates that the carotenoid-rich component is included solely for the purpose of adding color to the diet. Therefore, we believe that if you want your fermented BSG-fed male birds to develop vibrant colors, you need to add a measured amount of supplemental carotenoids to their feed rather than rely on the fermented BSG alone to provide the color.

Proposed experimental framework and predictions

Because the specific effect of fermented BSG on guppies has not been tested, we propose a three-phase design that separates growth, coloration and reproduction (Fig. 3, Table 3). Phase 1 would compare juvenile growth on a control diet and diets with graded inclusion of fermented BSG, with an unfermented BSG treatment at the same level as a control for the fermentation effect. Phase 2 would use adult males to assess colour with standardised photography and colourimetry, with and without added carotenoids. Phase 3 would follow breeding females over at least three consecutive broods. Diets should be formulated to be isonitrogenous and isoenergetic, and the proximate composition, fibre fraction and any carotenoid content of the fermented material should be analysed before use. Treatments should be replicated in independent tanks, with the tank as the experimental unit.

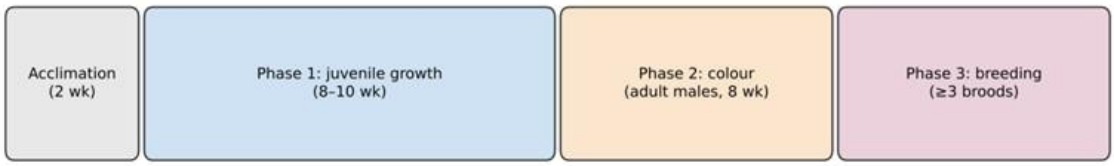

Figure 3: Proposed three-phase experimental design for testing fermented brewery spent grain in guppy diets.

Table 3: Outcome measures and testable predictions for dietary fermented brewery spent grain (BSG) in guppies.

Outcome	Key measurements	Prediction (hypothesis)	Main risk
Growth	Final weight, SGR, FCR, survival, apparent digestibility	Low–moderate inclusion of fermented BSG maintains growth; raw BSG at the same level performs worse	Fibre dilutes energy; lower intake
Coloration	Spot area, a*/b* colourimetry, skin carotenoids	No improvement unless carotenoids are supplied; fermentation may protect pigment indirectly	BSG lacks carotenoids
Fry production	Fry per brood, fry weight and survival, brood interval	Maintained at low inclusion; reduced at high inclusion	Female condition, intake
Sustainability	Feed cost per kg gain; fishmeal replaced	Lower cost at equal performance	Processing energy and logistics

Note: These are hypotheses derived from the literature, not results. a*/b*, skin redness/yellowness; SGR, specific growth rate; FCR, feed conversion ratio.

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Sustainability and practical considerations

The case for BSG rests on circularity: a by-product available throughout the year (Mussatto *et al*., 2006) is converted into feed protein, lowering reliance on marine ingredients that remain central to aquafeeds (Naylor *et al*., 2021). The review by Geremia *et al*. (2026) cautions, however, that these benefits must be verified through life-cycle assessment because transport, processing energy and emissions could offset the advantage; this applies equally to small-scale ornamental farms. For many tropical growers located close to a brewery, they have short delivery distances as well as the ability to use inexpensive solid state fermentation. However, there will always be several practical limitations that need to be overcome before there can be a successful commercial application, including but not limited to, the drying process, storage of the product, and maintaining consistent quality.

Conclusions

A review of the literature for food-fish species indicates that fermentation may enhance the utility of brewery spent grain as an alternative protein/energy source; particularly, by increasing the digestibility of the fibrous carbohydrate component of the spent grain. Fermented spent grain can be used up to approximately 50% of the conventional protein requirement (or less) in a diet. At present, there are no reported studies regarding the use of fermented spent grain in diets fed to guppies. Based upon the information available, it is anticipated that the lower inclusion levels of fermented spent grain would provide the same or better performance relative to standard diets at a lower feed cost. It is also expected that higher inclusion levels of fermented spent grain would result in reduced performance. Finally, it is estimated that color development in the fish would be primarily affected by carotenoid supplementation rather than by the spent grain itself. The most appropriate course of action would be to conduct a multi-phase, replicated study similar to what has been described herein. This paper provides a synthesis of the current body of knowledge related to the utilization of fermented spent grain in fish diets as a rationale for conducting such research.

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Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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