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Impact of banana peel and cocoa husk on growth performance, microbial communities, and skin pigmentation in goldfish (*Carassius auratus*) and Thaila (*Catla catla*)

Aqsa Ameen[1], Muhammad Ahmad[2*], Shakeela Parveen[1]

[1]Fish Microbiology & Immunology Laboratory, Department of Zoology, Wildlife and Fisheries, University of Agriculture, Faisalabad 38040, Pakistan
[2]College of Fisheries, Huazhong Agricultural University, Wuhan 430070, China

Abstract
Carassius auratus and *Catla catla* are polyculture species where growth and intensification have adverse effects on water quality, raising the risk of infection and disease prevalence. Due to these factors, the survival rate of farm fish is reduced. The demand for aquaculture continues to rise with human population growth, emphasizing the importance of well-formulated feeds in aquaculture success. High-quality feed can be prepared using industrial byproducts. It leads to minimizing feed expense, controlling disease outbreaks, and increasing net profit. This research work was conducted to study the impact of banana peel and cocoa husk on growth, microbial community, and pigmentation in *C. catla* and *C. auratus*. For this purpose, 30 specimens each of *C. catla* and *C. auratus* were randomly assigned to three groups: control (T_0) and experimental (T_1 and T_2). T_0 received commercial feed, whereas T_1 and T_2 were fed banana peel and cocoa husk diets at 2% body weight, respectively. For statistical analysis, a 2-factor factorial under CRD was performed. In the experimental group, length, weight, and specific growth rate (SGR) were non-significant between the species, but showed significant differences compared to the control group. In comparison to the control group, the bacterial count and pigmentation in the experimental group were significant. Because of their carotenoids and antioxidant qualities, banana peel and cocoa husk increased both species' immunological responses and pigmentation. Finally, integrating banana peel and cocoa husk into the diet of *C. auratus* and *C. catla* holds potential benefits in terms of reducing intestinal microorganisms, improving growth, and enhancing pigmentation of the fish species.

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Introduction

The aquaculture sector is one of the fastest-growing food-producing sectors in the world, and it is a promising source of protein and income. Although the growth in this sector seems to be phenomenal, disease outbreaks have become a significant limiting issue, with the infrequent consumption of antibiotics and chemotherapeutics emerging as the primary way to address them (Roh and Kannimuthu, 2023). These practices can cause environmental degradation, antimicrobial resistance, and health problems for the animal and human populations (Vaseeharan and Thaya, 2014; Muteeb

***CONTACT** Muhammad Ahmad, College of Fisheries, Huazhong Agricultural University, Wuhan 430070, China

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et al., 2023).

To overcome these obstacles, natural feed additives, especially polysaccharides and bioactives of plants, are becoming a promising, eco-friendly alternative to artificial substances and antibiotics (Karaket et al., 2021). The bi-directional advantage of feeding aquaculture with plant waste products is that it mitigates the limitations of waste disposal into the environment, and offers bioactive compounds that may boost fish growth, immunity, and pigmentation (Caipang et al., 2019). Fish need nutritional supplements for their natural skin pigment, since they do not produce sufficient carotenoid pigment. High-quality diets also help the overall fish health and resilience to diseases. The non-nutritive growth enhancers may foster fish performance and feed efficiency at minimum inclusion levels (Rani et al. 2014; Brum et al., 2025; Huang et al., 2025).

Catla catla (Thaila), which is a freshwater carp and a member of the family Cyprinidae, is used extensively in South Asian aquaculture, since it contains a large amount of protein, grows rapidly, and is compatible with other carp species (Saleem et al., 2022). It is a surface and mid-water feeder with a diet consisting of phytoplankton, insects, and small crustaceans. Commercial carp farming has become well-established in countries such as India and its neighbors, where feed represents a major component of production costs (Khan and Khan, 2022). *Carassius auratus* (Goldfish) is another Cyprinid and one of the most widely distributed ornamental species globally. It is recognized as such due to its resilience, ability to adapt to a variety of environments, and castle-protected genetic modifications that have produced the goldfish in many different color varieties (Mokhtar et al., 2025). However, native goldfish were initially grey or silver; a natural genetic mutation during the Jin Dynasty (265-420 AD) resulted in the reddish-orange coloration that is characteristic today (Mondal et al. 2018; Chen et al., 2020). Carotenoids such as β-carotene, astaxanthin, lutein, and canthaxanthin, which are stored in chromatophores in the skin, are primarily responsible for the rich color of ornamental fish. In addition to their aesthetic properties, carotenoids have antioxidant roles, which may protect fish against oxidative stress. The ornamental fish trade grows by approximately 20 percent each year at the domestic level, and a large number of varieties of freshwater ornamental fish are traded worldwide (Munguti et al., 2024).

The byproduct of cocoa processing, known as cocoa husk, makes up 70-75 percent of the total weight of the fruit, and produces 700-750 kg of cocoa pod husk per ton (Campos-Vega et al., 2018). It is rich in non-starch polysaccharides, lignin, phenolic acids, chlorophylls, carotenoids, and xanthophylls, along with minerals, dietary fiber, and bioactive phytochemicals (Loullis and Pinakoulaki, 2018; Soares and Oliveira, 2022). Cocoa husk contains pectin with antibacterial properties against several pathogenic bacteria (*Klebsiella pneumoniae*, methicillin-resistant *Staphylococcus aureus*, *Escherichia coli*, *Salmonella paratyphi*, *Pseudomonas aeruginosa,* and *Bacillus cereus*), and fungi (*Candida albicans*, *Trichophyton rubrum*, and *Aspergillus niger*), phytosterols with health-promoting functions, and polyphenols such as anthocyanins that possess strong antioxidant and antimicrobial activities (Vanitha and Khan, 2019). β-glucan and inulin are dietary fiber compounds that lead to enhanced digestion, nutrient absorption, and metabolic health (Edo et al., 2025). Cocoa husk is potentially a useful functional feed ingredient applicable to aquafeeds; cocoa husk has the potential to improve fish growth and immunity, and promote fish health due to a balanced microbial community inside fish (Braojos et al., 2020).

Banana (*Musa* spp.) is among the world's most widely consumed fruits, and its peel, constituting a major proportion of the fruit's weight, is a major agricultural byproduct (Yasin et al., 2025). Banana peels contain high levels of dietary fiber (cellulose, hemicellulose, and pectin), proteins, minerals, and a variety of bioactive compounds such as flavonoids, tannins, saponins, alkaloids, and polyphenols (Vu et al., 2018). These phytochemicals are antibacterial, antifungal, and antioxidants, which inhibit pathogen metabolism and protect against oxidative stress (Wani and Dhanya, 2025). Carotenoids like lutein, β-carotene, α-carotene, and violaxanthin, present in banana peels, can enhance pigmentation and optimize nutritional utilization (Giri et al., 2016).

The nutritional and bioactive properties of banana peel and cocoa husk make them fascinating dietary supplements in aquaculture, where the use of agricultural waste can contribute to sustainable production and improve fish health and quality. The marketing value of ornamental fish like *Carassius auratus* can be increased by improving the pigmentation on the body, whereas in food species like *Catla catla,* production can be increased by improving growth performance and microbial balance. Furthermore, these plant materials are anticipated to have antimicrobial capabilities that help reduce the use of antibiotics in fish aquaculture. The goal of this study was to evaluate the effects of banana peel and cocoa husk supplementation on (i) growth performance, (ii) the microbial community, and (iii) skin pigmentation in *C. auratus* and *C. catla*. The findings from this study are intended to provide insights into an environmentally-friendly approach to feed formulation that can boost aquaculture output while reducing the environmental and health hazards of synthetic additives.

Material and Methods

Samples collections

The experimental trial was carried out at the Fisheries Research Farm (FRF), located at the Department of Zoology, Wildlife and Fisheries, University of Agriculture, Faisalabad, Pakistan. The experiment was conducted for two months. starting from 20th October 2023 to 20th December 2023. A completely randomized design was applied in this experiment. Thirty (30) specimens each of *Catla catla* and *Carassius auratus* were carefully handled and taken from the FRF's earthen research ponds for study. All fish were first treated with a 1% sodium chloride (NaCl) bath and then subjected to an acclimatization period of one week before the start of the experiment.

Fish stocking

After the acclimation phase, the fish were transferred to their respective aquariums. Every day, approximately one-third of the water was replenished with freshwater. To ensure water quality, factors such as temperature (20-24 °C), pH (7.0-7.1), and dissolved oxygen (5-7 mg L^{-1}) were regularly measured and monitored. Each group included two species, *C. catla* and *C. auratus*, because of polyculture behavior. Fishes were fed with the following types of diet once each day at 10 a.m:

T_0: Commercial feed 2% of their body weight
T_1: Special feed containing banana peel at 2% of their body weight
T_2: Special feed containing cocoa husk at 2% of their body weight

Diet preparation

Banana peels were collected locally and properly washed with water to remove dirt and bacteria. Then, the peels were dried at a low temperature in shady areas for several hours until they became brittle and crumbly. The dried banana peels were crushed into a fine powder using a food processor, blender, or coffee grinder. To remove lumps and enormous particles, the powder was sifted through a fine-mesh screen. Cocoa husk supplements were commercially accessible. Each feed was packaged in airtight containers to preserve it from moisture and contamination, and then stored in a cold, dry place away from direct sunlight to keep its quality, nutrition, and palatability until utilization.

Determination of growth performance

During the feeding trial, weight gain (g), length gain (cm), and SGR (specific growth rate) were measured by the method of Islam et al. (2023).

$$Weight\ gain = Final\ weight(Wf) - Initial\ weight(Wi)$$

$$Length\ gain = Final\ length(cm) - Intial\ length(cm)$$

$$Daily\ weight\ gain\ (DWG) = \frac{Mean\ of\ final\ weight\ (g) - Mean\ of\ intial\ weight\ (g)}{Days} \times 100$$

$$SGR(\%) = \frac{\ln(W2) - \ln(W1)}{T2 - T1} \times 100$$

Carotenoid extraction and analysis

Fishes were caught from each aquarium, and the samples were collected from the skin. First, visual inspection of skin coloration was determined at the start and end of the experiment. The fish samples were finely ground using a mortar and pestle, then suspended each in 10 mL of acetone in a 15 mL centrifuge tube, securely capped with screw caps. The tubes were covered with an aluminum foil and subjected to vortex mixing for 1 minute. Following vortex mixing, the solutions were left at room temperature for 5 minutes before being centrifuged at 2034 rpm for 10 minutes. The resulting supernatant was filtered through a 0.45-micrometer membrane filter, and optical densities were measured at a wavelength of 471 nm using a spectrophotometer. The values were recorded for further analysis (Rønsholdt et al. 2001).

Preparation of gut microbial media

Samples of Thaila and goldfish were collected in clear and sterilized polythene bags, immediately transported to the laboratory, and refrigerated for further analysis. To prevent contamination, the preserved specimens of fish were dissected to extract their guts using sterile dissecting tools. During this procedure, the sloughed-off matter was put into an Eppendorf tube containing a 9% salt solution and shaken with an electric shaker. Total bacterial count using media solutions of the nutrient agar (NA) was prepared by dissolving 2.80 g in 100 mL of distilled water. The mixes were autoclaved for over 15 minutes at 121 ºC using the process described by Adejonwo et al. (2020) and Ogunshe and Olabode (2009). After completing this procedure, the culture media solution was taken out of the autoclave and transferred onto individual Petri dishes so that it could harden into a solid gel-like consistency. The quadrant streaking approach was used to cultivate fish gut microbes on media (Sanders, 2012). After incubating the Petri plates for 24 hours at 37 ºC, colony-forming units (CFUs) were measured with a digital colony counter using the following formula:

$$Total\ viable\ count = Average\ no.of\ colonies \times Dilution\ factor$$

Statistical analysis

The research data was statistically analyzed. The two-factor factorial ANOVA was used in a completely randomized design (CRD) to assess the main and interaction effects of species and treatments, with a level of significance of *P*-value ($\leq$ 0.05).

Results

Growth performance

Main and interaction effects showed non-significant results (*P* > 0.05) in length, weight, and specific growth rate (SGR), which means that banana peel and cocoa husk had the same effect on goldfish and Thaila, but as compared to the control group, the experimental group had significant results shown in ANOVA (Table 1) and Figure 1.

Table 1: Analysis of main and interaction (S × T) effect between species (S) and treatments (T), and between the treatment groups using the two-way factorial ANOVA

	Length (cm)		Weight (g)		SGR%		Microbial growth (CFU 10^6)		Pigmentation at 471 nm (wavelength)	
SOV	*F*-Value	*P*-Value	*F*-Value	*P*-Value	*F*-Value	*p*-Value	*F*-Value	*P*-Value	*F*-Value	*P*-Value
S	77.96	<0.001***	6.55	0.014**	0.00	1.000^{ns}	0.00	0.985^{ns}	11.47	<0.001***
T	11.22	<0.001***	5.05	0.011**	0.19	0.829^{ns}	700.65	<0.001***	100.91	<0.001***
S×T	0.90	0.414^{ns}	0.10	0.905^{ns}	0.13	0.878^{ns}	4.90	0.011**	27.39	<0.001***

SOV, Source of variation; SGR, Specific growth rate

The species effect (*P* < 0.001) indicates that goldfish grew significantly longer than Thaila. Similarly, the treatment effect (*P* < 0.001) revealed that the feed type influenced length gain, with banana peel (T_1) resulting in the highest mean length, as presented in Figure 1a.

Catla catla with treatment cocoa husk (T_2) showed the highest average weight. The ANOVA results demonstrate that both treatment and species (*P* < 0.05) had substantial effects on weight. However, the treatment-species interaction (*P* > 0.05) was not significant, suggesting that the treatment's impact was constant for both species. Figure 1b graphically indicates that both treatments and species have an impact on fish mean weight. The scatter plots (Figure 1c) show a clear positive relationship between length and weight in both fish species. Across all lengths, fish in the cocoa husk treatment (T_2) consistently weighed more than those in the banana peel (T_1) and control (T_0), indicating enhanced growth performance. This trend was more pronounced in goldfish, where the separation between the treatments was greater, while in Thaila, the differences were smaller, but still visible. Overall, the results suggest that dietary treatments, particularly coca husk, improved weight gain without altering the basic length–weight growth pattern. Thus, overall, both species and treatments significantly affected fish weight on their own, but they did not have an interaction.

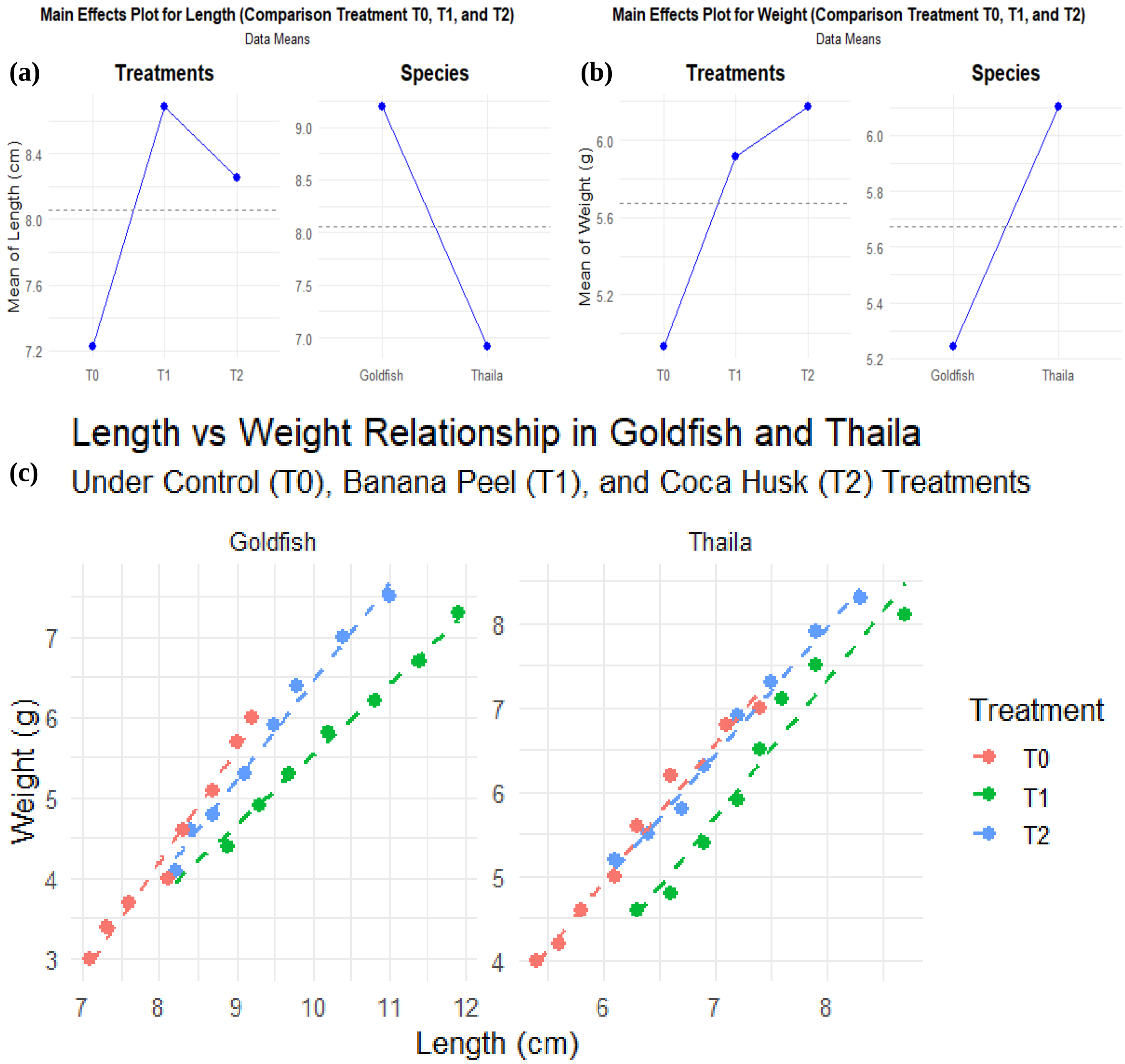

Fig. 1: Main effects plots showing (a) length gain, and (b) weight gain in fish subjected to different treatments: Control (T_0), Banana peel (T_1), and Cocoa husk (T_2). (c) Scatter plot illustrating the direct relationship between length (L) and weight (W) gain in goldfish and thaila (L ∝ W)

Specific growth rate (SGR)

In goldfish and catla, SGR plays a significant role. Non-significant ($P > 0.01$) species treatment (Table 1) interaction showed that banana peel was more effective than cocoa husk; however, the treatment impact on SGR did not depend on species (Figure 2a).

In the present study, the SGR effect on the length and weight of goldfish and Thalia was observed under different treatments. The T_2 treatment produced the highest SGR in both goldfish and Thalia, regardless of length or weight. The T_0 showed the lowest SGR, especially in Thalia, despite moderate body size. The treatment effects were more pronounced than species differences in influencing SGR. Fish with greater length and weight generally had higher SGR, but this trend was amplified under T_2. Thalia in T_0 was both lighter/shorter and had the lowest SGR, showing poor growth performance. Goldfish in T_1 outperformed Thaila in SGR despite being slightly smaller in size, as shown in Figure 2b.

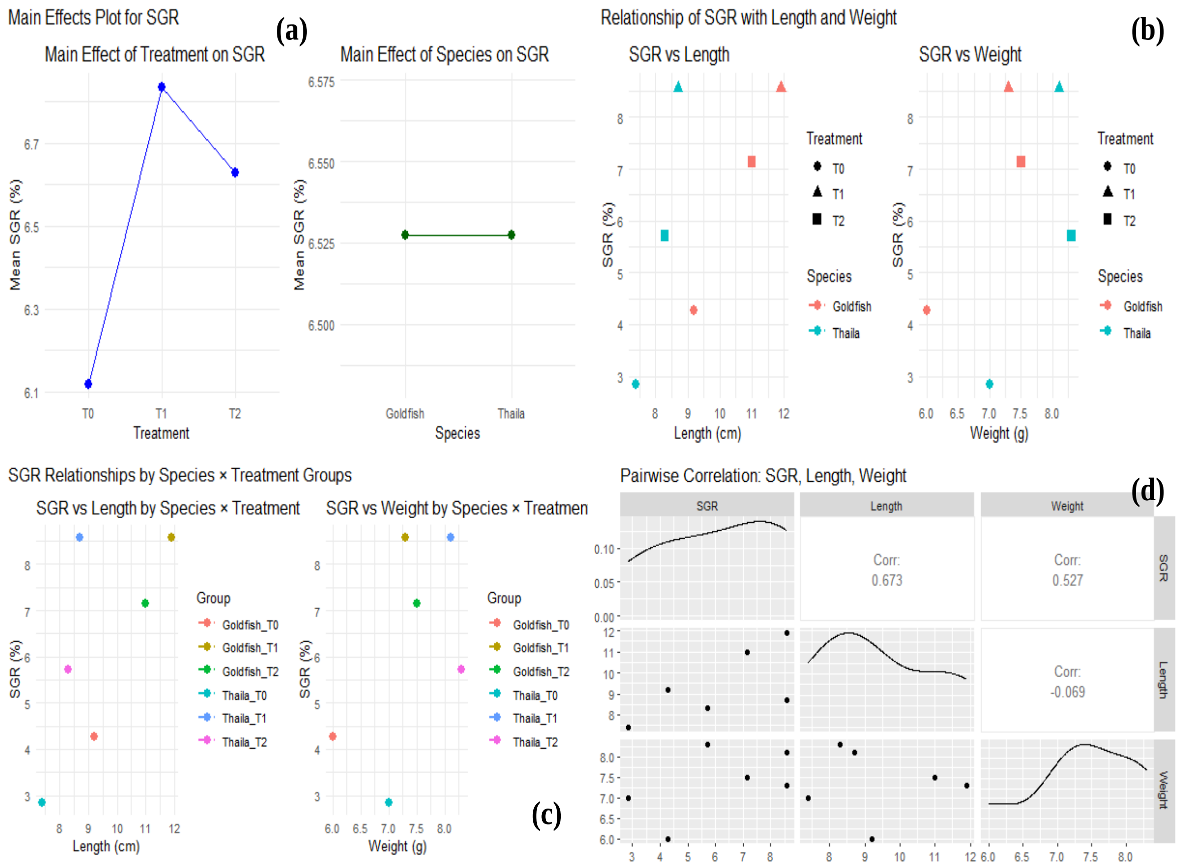

Fig. 2(a): The main effects plot of specific growth rate (SGR) across different treatments: Control (T_0), Banana peel (T_1), and Cocoa husk (T_2). (b) Comparison of SGR with the direct relationship between length and weight of the species. (c) Scatter plot showing the relationship between SGR, species, and treatment groups. (d) Pairwise correlation matrix among SGR, length, and weight.

The SGR–length and SGR–weight plots (**Figure 2c**) show that T_2 treatment consistently produced the highest SGR in both goldfish and Thaila, while T_0 had the lowest growth rates, especially in Thaila. Goldfish generally outperformed Thaila at the same treatment level, except in T_2, where both species achieved similarly high SGR. Length appears slightly more aligned with SGR trends than weight, reflecting the moderate correlation found in the pairwise analysis. These results highlight that the treatment effects had a stronger influence on growth than species differences.

The pairwise correlation plot (**Figure 2d**) shows that SGR had a moderate positive correlation with both length (r = 0.673) and weight (r = 0.527), indicating that fish with greater length or weight tend to have higher growth rates, with length being a slightly stronger predictor. In contrast, length and weight were weakly and negatively correlated (r = –0.069), suggesting that longer fish are not necessarily heavier in this dataset. Overall, growth performance is more closely linked to size traits individually than to the relationship between length and weight.

Total internal microbial count

Important information about the variety and quantity of microorganisms residing in the fish's gastrointestinal tract was obtained by analyzing the overall microbiological composition of intestinal samples taken from the experimental and control groups of goldfish and catla. The ANOVA (**Table 1**) indicates that the antibacterial impact of banana peel and cocoa husk feeds varies between the two species, as indicated by the main and interaction effects, which indicate significant results ($P < 0.05$).

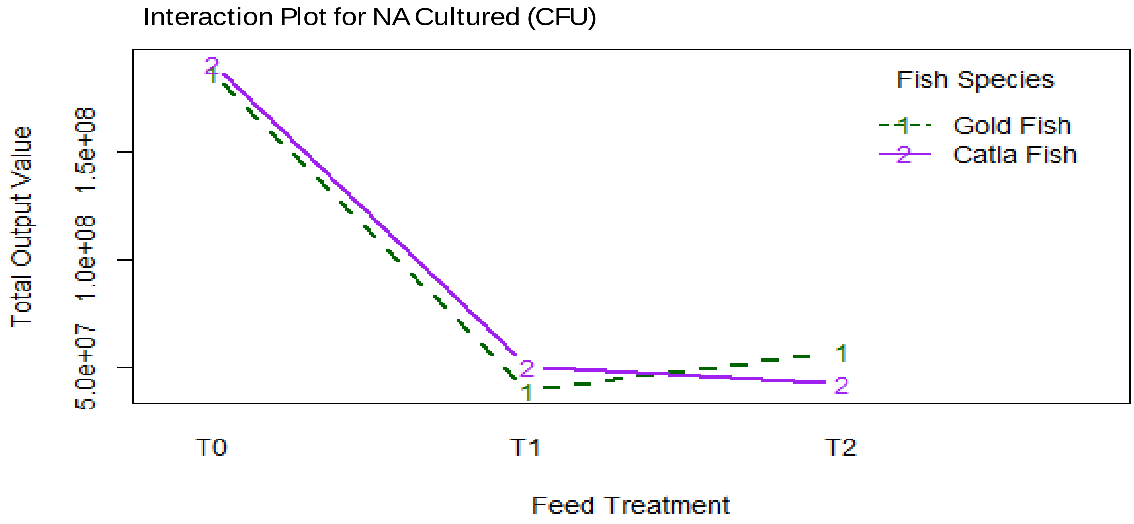

Fig. 3: Interaction plot of intestinal bacterial growth on nutrient agar (NA) across different treatments: Control (T_0), Banana peel (T_1), and Cocoa husk (T_2)

The nutrient agar (NA) media was used for culturing the gut samples of both fish species, where the maximum and minimum numbers of colonies were noted and estimated along with their colony-forming unit (CFU) value. Banana peel significantly reduced bacterial growth in goldfish more than in catla, but the difference was minimal. In cocoa husk treatment, CFU levels remained low for both species, but it was more effective in reducing bacterial growth in catla than in goldfish. Although there were minor species differences, both treatments had a similar positive impact on goldfish and catla, graphically represented in Figure 3.

Pigmentation analysis

Carotenoids like canthaxanthin, lutein, astaxanthin, and zeaxanthin are crucial for fish coloration and general health. Fish must get these carotenoids from their feed because they are unable to produce them internally. Carotenoids are responsible for the appealing skin coloration and beauty of ornamental fish, which affects price and demand in the market. The pigmentation effect of banana peel and cocoa husk feeds differed between the two species, as indicated by the ANOVA (Table 1) and illustrated in Figure 4. All main and interaction effects indicated significant results ($P < 0.001$).

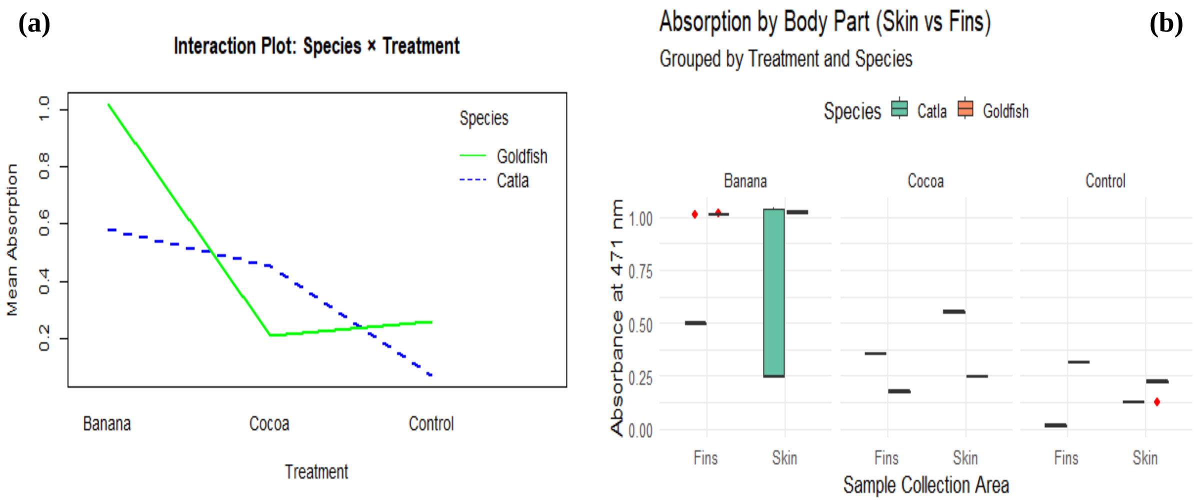

Fig. 4(a): Interaction plot of pigment absorption at 471 nm under treatments: Control (T_0), Banana peel (T_1), and Cocoa husk (T_2). (b) Comparison of pigment absorption between skin and fins at 471 nm across the same treatments.

In the experimental groups, it was observed that banana peel had a high pigmentation influence on goldfish and absorption drops in catla. Cocoa led to high absorption in catla and a slightly lower response in goldfish. While examining absorption, the interaction suggests that the treatment efficacy differs by species, as graphically represented in **Figure 4a**.

Across all groups, banana treatment produced the highest pigment absorption, particularly in catla skin and goldfish fins, indicating a strong dietary influence on pigment deposition (**Figure 4b**). The cocoa treatment showed moderate effects, while the control consistently had the lowest absorbance, reflecting baseline pigment levels. Skin generally exhibited higher absorbance than fins, suggesting greater pigment accumulation in skin tissue. These results imply that dietary supplementation, especially with banana peel, can markedly enhance pigment or carotenoid content in fish.

Discussion

The current study's results show that both feed types, namely cocoa husk and banana peel, significantly improved the weight and length of both fish species. Likewise, Zargaran Hoseini and Chelemal Dezfulnejad (2018) experimented on common carp (*Cyprinus carpio*) to assess the impact of banana peel powder on survival, growth, and body composition; there was a prominent impact of banana peel on protein content, efficiency ratio, and growth rate between the control group and the banana peel-supplemented group. In our study, significant ($P < 0.05$) species and treatment effects showed that banana peel increased length and weight in goldfish, and cocoa husk had a positive impact on the growth of Thaila, as shown in **Figure 1**. A previous study on the replacement of maize with cocoa pod husk in the diet of tilapia (*Oreochromis niloticus*) also supported our research, and the results showed that cocoa pod husk replacement had prominent effects on growth and survival, and it also reduced the feed cost (Ashade and Osineye, 2013). The cocoa husk has been reported to possess reasonable amounts of dietary fibers, polyphenols, methylxanthine, and phytosterols, which can be judiciously exploited in various food and health products (Belwal et al., 2022).

Non-significant SGR showed that goldfish and Thaila had the same response to both diets. The SGR's correlation with weight and length revealed that both food supplements improved growth performance, while goldfish exhibited higher growth responsiveness than Thaila. Growth rate continued to rise with body length rather than with body mass, as shown in Figure 2. Likewise, Metwally and El-Gellal (2009) studied the impact of plant waste on body composition and growth performance of fish, and the results showed that adding plant waste material to the fish diet helped promote growth, enhanced the antioxidant activity, and decreased mortality in fish. Falaye and Jauncey (1999) studied the digestibility, nutrient utilization, and acceptability of cocoa husk in tilapia (*Oreochromis niloticus*). Positive weight gain and voracious consumption indicate acceptability to the tilapia, which was also evident from our work.

The amounts of microbes in the experimental and control groups, as well as in the catla and goldfish within each group, fluctuated significantly. It has been reported that the antioxidant qualities of banana peel and cocoa husk, including anthocyanins, phenolic compounds, and pectin, help prevent several diseases (Vu et al., 2018). Ugoala et al. (2016) explained that for long-term sustainability, the use of natural products is necessary. These products have diverse effects, like antimicrobial and antioxidant effects, and they do not cause any harmful impacts because they are natural. A previous study also reported the antibacterial effect of cocoa husk phenolic extract on *Escherichia coli* (Diniardi et al., 2020). The results showed that phenolic compounds denatured the cell walls of bacteria and stopping metabolic activity and leading to death. However, Giri et al. (2016) observed that when Rohu (*Labeo rohita*) was fed on banana peel, the prominent improvement of immune functions such as catalase activity, lysozyme, superoxide dismutase, and leukocyte phagocytes was observed in the high concentration group. Comparably, our study revealed that the ability to combat diseases increased both in *C. auratus* and *C. catla.* Rita et al. (2020) studied the antioxidant and antibacterial activity of banana peel methanol extract in Bali and resulted in suggesting that antibacterial and antioxidant capacity were positively correlated with the phenolic and flavonoid contents.

Several ornamental fish species, including goldfish (*Carassius auratus*), koi (*Cyprinus carpio*), rainbow fish (*Melanotaenia praecox*), and swordfish, show an increase in the intensity of the brightness of their body color when given different sources of natural ß-carotene (Rana et al., 2022). Fish and other aquatic animals cannot produce carotenoids in their bodies; only plants and protists (algae, fungi, and bacteria) can synthesize carotenoids. Carotenoids are accumulated from microalgae or phytoplankton via the food chain in the natural aquatic environment (Kurnia et al., 2019). The pigmentation effect of banana peel and cocoa husk feeds is evident, as indicated by the ANOVA (**Table 1**), which indicated significant findings ($P < 0.05$) for all main and interaction effects. Fish's increased color intensity is a function of feed quantity, particularly color components in feed composition, meaning that the higher the amount of carotenoids in the feed, the higher the chroma value (Gupta et al., 2007). Banana peel had more pigmentation incorporation in goldfish due to high carotenoid content and absorption drops in catla, as shown in **Figure 4a**. Fish skin color pigmentation is enhanced by two primary variables: internal and external variables. Internal variables, sometimes referred to as permanent factors, include a fish's age, sex, genetics, and capacity to absorb nutrients from food. External variables include light, feed, and water quality (Eriegha and Ekokotu, 2017). Fins of catla absorbed a higher color pattern than skin under banana peel, and coloration was low both in fin and skin due to cocoa husk, irrespective of fish species, as shown in **Figure 4b**.

The skin coloration shows that banana peel, as a carotenoid source, is better suited to be supplied to fish than any other carotenoid used for improving skin pigmentation. Beta-carotene is transformed into astaxanthin in the gut and gives bright red coloration to skin and flesh (Lestari et al., 2019). Carotenoids primarily function as photoprotectors in the context of photosynthetic processes, and other organisms within the food web benefit from their ability to combat UV radiation as well as their antioxidant capabilities against free radicals and reactive oxygen species (ROS) (Maoka, 2011). The study of Pike et al. (2010) on spined sticklebacks (*Gasterosteus aculeatus*) supported our results that fish on the low-carotenoid diet showed a decline in sustained swimming performance and retarded growth as compared to the fish on the high-carotenoid diet. These findings were similar to those of our research work.

Conclusion

Substitution of commercial feed with banana peel and cocoa husk positively impacted the level of feed efficiency, feed consumption, and energy retention in *C. auratus* and *C. catla*. Additionally, it increased digestive enzyme activity and enhanced growth performance. Flavonoids and phenolics in feeds had antioxidant and antibacterial properties and boosted immunity by increasing positive microbes and suppressing harmful bacteria in both fish species. Without the addition of carotenoid supplementation, ornamental fish developed faded coloration. Banana peel and cocoa husk were rich in carotenoids, so they enhanced pigmentation in Thaila and goldfish. Carotenoids also enhanced the feed utilization and had a positive effect on metabolism. In conclusion, adding plant waste material to the fish diet helps to promote growth, enhances the antioxidant activity and color absorbance, and decreases mortality in fish. Further research may be done to find out its applications for a variety of aquatic species for optimal health management.

Author(s), Editor(s) and Publisher's declarations

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Contribution of authors
Conceptualization and design of the study: AA, SP, MA. Conduction of experiments: AA, MA. Data collection, visualization, and interpretation: AA, SP, MA. Formal statistical analysis: AA, MA. Writing of first draft: AA, SP. Proofreading and approval of the final version: AA, MA, SP

Permissions and ethical compliance
This work was approved by the Institutional Ethical Review Board/Committee (IERB/C) of the University of Agriculture, Faisalabad, Pakistan (Approval number UAF/Zool/211 dated 23-05-2023).

Handling of bio-hazardous materials
The authors certify that all experimental materials were handled with great care during collection and experimental procedures. After completion of the study, all materials were properly discarded to minimize/eliminate any types of bio-contamination(s).

Supplementary material

No supplementary material is included with this manuscript.

Conflict of interest

The authors declare no conflict of interest.

Availability of primary data and materials

As per editorial policy, experimental materials, primary data, or software codes are not submitted to the publisher/Journal management. These are available with the corresponding author (s) and/or with other author(s) as declared by the corresponding author (s) of this manuscript.

Authors' consent

All authors have critically read this manuscript and agreed to publish in IJAaEB.

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