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Effectiveness of Various Natural β-Carotene Sources in Feed on the Color Brightness of Goldfish (*Carassius auratus*)

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Abstract: This study aimed to analyze the effect of incorporating several natural sources of β-carotene into feed on improving the color brightness of goldfish. An experimental method was employed using a completely randomized design (CRD) with four treatments and three replications: P1 as the control, P2 with carrot powder, P3 with papaya powder, and P4 with tomato powder, each added to the feed at the same dosage. Color brightness was measured using a color-chart-based scale analysis, and the resulting data were analyzed using one-way ANOVA followed by Tukey's post hoc test. The results showed no significant differences among treatments during the initial observation period ($F = 1.916$; $p = 0.129$). However, significant differences were observed in the subsequent assessment ($F = 461.230$; $p < 0.001$; $\eta^2 = 0.894$). The highest color brightness was recorded in P2, which received carrot powder, followed by P3 with papaya powder, P4 with tomato powder, and P1 as the control. These findings indicate that natural sources of β-carotene have a strong effect on enhancing the color brightness of goldfish. They also provide practical implications for developing natural feeds based on locally available ingredients for ornamental fish culture.
Keywords: Goldfish; ornamental fish; β-carotene; color brightness, natural feed

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INTRODUCTION

Goldfish (*Carassius auratus*) are among the most economically valuable freshwater ornamental fish, with market demand continuing to increase because their aesthetic value is strongly influenced by the intensity and stability of body coloration. In the ornamental fish industry, body color is a key indicator of quality and directly determines the market value of fish (Kadarini et al., 2021; Ibrohim et al., 2024). Biologically, fish coloration is produced by the activity of chromatophore cells containing pigments, particularly carotenoids, which are obtained from the diet and subsequently absorbed and deposited in fish tissues. β-carotene, as one type of carotenoid, functions as a pigment precursor that contributes to the formation of red, orange, and yellow coloration in ornamental fish (Khairunnisa et al., 2020). The biological process of color formation in fish can be described through three stages: input, in the form of carotenoid intake from feed; process, involving pigment absorption and deposition in chromatophores; and output, reflected in the intensity or brightness of body coloration. However, fish cannot synthesize carotenoids endogenously; therefore, all pigment requirements must be supplied through the diet (Lestari et al., 2019). A deficiency of dietary carotenoids may reduce chromatophore activity, causing fish coloration to become pale and decreasing visual quality. Accordingly, the use of natural β-carotene sources in feed represents an important strategy for improving pigmentation in ornamental fish. Several natural ingredients, such as carrot (*Daucus carota*), papaya (*Carica papaya*), and tomato (*Solanum lycopersicum*), are known to contain carotenoids, including β-carotene and lycopene, which have the potential to enhance fish color quality (Audina et al., 2020; Florida et al., 2022).

Nevertheless, ornamental fish farming still faces challenges related to inconsistent color brightness, largely due to suboptimal feed quality in terms of pigment content. Previous studies have shown that supplementation with natural β-carotene sources can enhance chromatophore activity and improve color intensity in fish (Budi, 2021; Oktaviani et al., 2015; Nur et al., 2024). In addition, the use of natural pigments is considered safer and more environmentally friendly than synthetic dyes (Luciana, 2023). However, most previous studies have examined only a single ingredient separately, thereby providing limited comparative evidence on the relative effectiveness of different β-carotene sources within the same experimental system. Moreover, many studies have not applied fully quantitative approaches to color measurement, resulting in findings that remain largely descriptive and visually based.

A more specific research gap lies in the lack of controlled comparisons among natural carotenoid sources with different pigment characteristics under equivalent experimental conditions, as well as the limited control of potential bias caused by differences in pigment concentration among ingredients. Carrot is known to contain high levels of β-carotene, which predominantly contributes to orange coloration (Sholihah, 2021). Papaya contains carotenoids associated with color stability (Florida et al., 2022), whereas tomato contains lycopene, which is more closely related to red pigmentation (Audina et al., 2020). These compositional differences may produce distinct pigmentation responses in goldfish. However, in many previous studies, pigment concentrations among ingredients were not standardized, which may have introduced bias in interpreting the effectiveness of each pigment source.

Based on these considerations, this study aimed to analyze the effects of different natural β-carotene sources in feed on improving the color brightness of goldfish (*Carassius auratus*). In this study, color brightness was defined as the visual intensity of fish body coloration observed using a color chart-based scale as a quantitative indicator of pigmentation change. Treatment effectiveness was evaluated based on changes in color brightness levels among treatments. This study used natural ingredient extracts in the form of carrot, papaya, and tomato powders incorporated into feed formulations. The findings are expected to provide scientific insight into the relationship between β-carotene intake, chromatophore activity, and improved fish coloration, while also supporting the development of more effective, standardized, and applicable natural feed formulations for sustainable ornamental fish culture.

METHOD

This study employed an experimental method with a quantitative approach to analyze the effects of adding various natural sources of β-carotene to feed on the color brightness of goldfish (*Carassius auratus*). The study was conducted for approximately 60 days in an aquaculture laboratory. A completely randomized design (CRD) was used, consisting of four treatments and three replications, resulting in 12 experimental units. The treatments were P1, control feed without β-carotene supplementation; P2, feed supplemented with carrot flour; P3, feed supplemented with papaya flour; and P4, feed supplemented with tomato flour.

All plant materials were processed through drying and grinding until they formed flour, after which they were incorporated into a standard formulated diet at the same dosage, namely 10% of the total feed weight. This dosage was determined based on previous studies on plant-based supplementation in ornamental fish diets. The use of a uniform dosage was intended to ensure that comparisons among treatments were equivalent. However, this study had a limitation because the actual β-carotene content of each ingredient was not standardized or measured. Therefore, potential bias may have occurred due to natural differences in β-carotene concentration among the ingredients, as carrots are known to contain higher β-carotene levels than papaya and tomato. Each experimental unit was randomly positioned to minimize environmental bias and ensure homogeneous rearing conditions across treatments.

The experimental animals consisted of 24 goldfish with an initial length of 4–5 cm and an initial body weight of 3–5 g. Fish were selected based on healthy and uniform conditions and were acclimatized for 5–7 days before treatment to reduce environmental stress. Rearing was carried out in aquaria measuring approximately 40 × 30 × 30 cm, each equipped with aeration and stocked at a density of two fish per aquarium. Environmental conditions were maintained within stable ranges throughout the rearing period, including water temperature of 26–28°C, pH of 6.5–7.5, dissolved oxygen above 3 mg/L, and fluorescent lighting with constant light intensity. A 12-hour light and 12-hour dark photoperiod (12L:12D) was applied to standardize the influence of light on fish pigmentation.

The basal diet used in this study was a commercial ornamental fish feed containing approximately 30–32% protein, 4–6% lipid, and carbohydrates as an energy source, which was then reformulated according to each treatment. Feed was provided two to three times daily to apparent satiation according to the feeding requirements of the fish. The experimental diets were prepared by mixing the basal feed with the additional ingredients, namely carrot flour, papaya flour, and tomato flour, which had been dried and ground. The mixtures were homogenized thoroughly before being administered to the fish. This process was intended to ensure an even distribution of β-carotene in the feed so that it could be consumed optimally and produce consistent effects on body pigmentation.

Color brightness was measured periodically using the Toca Colour Finder (TCF) method and digital color analysis based on RGB values (Red, Green, and Blue). Observations were conducted once every seven days during the 60-day rearing period to monitor gradual changes in pigmentation. Data were collected by photographing the fish with a digital camera under standardized lighting conditions to avoid color bias, using constant light intensity and a neutral background. Images were captured from the same position for each fish, covering the dorsal region, lateral body surface, and abdominal area to ensure consistency across observations. The images were then analyzed using color analysis software to obtain RGB values, which were subsequently converted into brightness values as an indicator of pigmentation changes in goldfish over time. Color brightness was calculated using the following formula:

Brightness = Final color value − Initial color value

In addition to color parameters, supporting parameters, including growth and survival, were also measured. Survival rate (SR) was calculated using the following formula:

SR (%) = (Nt / N0) × 100

Note:
SR = survival rate (%),
Nt = number of fish at the end of the rearing period,
N0 = number of fish at the beginning of the rearing period.

The data obtained were analyzed using one-way analysis of variance (ANOVA) at a 95% confidence level ($\alpha = 0.05$) to determine the effects of treatments on the observed variables. When significant differences were detected, Tukey's honestly significant difference (HSD) test was performed to identify differences among treatments. This analysis was conducted to determine the most effective treatment for increasing the color brightness of goldfish. The data collected during the study were analyzed using a quantitative statistical approach. The primary parameter analyzed was the color brightness of goldfish, while supporting parameters included absolute weight gain and absolute length gain.

Absolute weight gain was calculated using the following formula:

$$W = Wt - W0$$

Note:
W = absolute weight gain (g),
Wt = mean fish weight at the end of the rearing period (g),
W0 = mean fish weight at the beginning of the rearing period (g).

Absolute length gain was calculated using the following equation:

$$L = Lt - L0$$

Note:
L = absolute length gain (cm),
Lt = mean fish length at the end of the rearing period (cm),
L0 = mean fish length at the beginning of the rearing period (cm).

RESULTS AND DISCUSSION

This study aimed to evaluate the effects of different natural β-carotene sources on the enhancement of color brightness in goldfish (*Carassius auratus*). The treatments consisted of P1 (control), P2 (carrot), P3 (papaya), and P4 (tomato). Data were analyzed using one-way ANOVA after the assumption of homogeneity of variance was fulfilled ($p > 0.05$).

Color Brightness of Goldfish

At the initial observation stage, or sampling 1, no significant difference in color brightness was observed among treatments ($F = 1.916$; $p = 0.129$). This result indicates that the dietary addition of natural β-carotene sources had not yet produced a measurable effect on fish body coloration during the early rearing period. The absence of a significant response at this stage may be associated with the gradual nature of carotenoid digestion, absorption, transport, and deposition in fish tissues. Carotenoids are lipid-soluble pigments; therefore, their absorption depends on feed matrix disruption, emulsification with lipid components, micelle formation, intestinal uptake, and subsequent transport to target tissues (Das & Biswas, 2016; Caramujo et al., 2017).

In contrast, the analysis at sampling 2 showed a highly significant difference among treatments ($F = 461.230$; $p < 0.001$; $\eta^2 = 0.894$). The η^2 value indicates a very strong treatment effect, suggesting that differences in the dietary β-carotene sources substantially contributed to variation in color brightness. This finding supports the general principle that ornamental fish depend on dietary carotenoids to improve body coloration because fish cannot synthesize carotenoid pigments de novo (Das & Biswas, 2016; Sathyaruban et al., 2021).

The mean color brightness values of goldfish in each treatment are presented in Table 1.

Table 1. Mean color brightness of goldfish in each treatment

Treatment	Mean Brightness	Notation
P1 (Control)	9.33	a
P2 (Carrot)	16.77	b
P3 (Papaya)	13.98	a
P4 (Tomato)	14.12	a

Note: Different letters in the same column indicate significant differences based on Tukey's HSD test at a 95% confidence level ($p < 0.05$).

Based on Table 1, treatment P2, which contained carrot flour, produced the highest mean color brightness and differed significantly from the other treatments ($p < 0.05$). In contrast, P1, P3, and P4 did not differ significantly from one another, as indicated by the same letter notation. These results suggest that carrot flour was the most effective natural β-carotene source for enhancing goldfish color brightness under the conditions of this study.

The difference between the ANOVA result and Tukey's post hoc test indicates that although the overall treatment effect was significant, not all treatment pairs differed significantly. This pattern may be explained by variation within each treatment group and by the relatively similar pigmentation responses produced by papaya and tomato. Although both ingredients contain carotenoid compounds, their pigment composition, stability, and bioavailability may differ from carrot-derived β-carotene, resulting in less pronounced color enhancement.

Mechanism of Carotenoid Metabolism and Pigment Deposition

Carotenoids play an important role in the formation of yellow, orange, and red coloration in fish. However, because fish cannot synthesize carotenoids endogenously, these pigments must be supplied through the diet (Das and Biswas, 2016; Sathyaruban et al., 2021). After ingestion, carotenoids are digested together with dietary lipids in the digestive tract, absorbed through the intestine, and transported via the bloodstream to target tissues. These pigments are then deposited in chromatophore cells, particularly xanthophores and erythrophores, which contribute to yellow, orange, and red coloration in the integument of ornamental fish (Caramujo et al., 2017; Das and Biswas, 2016).

The superior response observed in the carrot treatment may be attributed to the relatively high β-carotene content and better pigment stability of carrot flour during feed processing. β-Carotene is associated with orange coloration and can act as an important pigment precursor in ornamental fish. Previous studies have also reported that carrot flour supplementation can increase color brightness in goldfish and other ornamental fish (Ahlam et al., 2019; Darsiani et al., 2025). In the present study, the higher brightness value in P2 suggests that carrot-derived β-carotene was more effectively absorbed, metabolized, and deposited in chromatophore cells than the carotenoids supplied by papaya and tomato.

By comparison, papaya and tomato contain different carotenoid profiles. Tomato is rich in lycopene, whereas papaya contains carotenoids in different forms and concentrations. Although these compounds may contribute to pigmentation, their conversion, absorption, and tissue deposition may not be as efficient as carrot-derived β-carotene for enhancing orange coloration in goldfish. Carotenoid structure is known to influence solubility, absorption, metabolism, antioxidant function, and tissue accumulation (Caramujo et al., 2017). Therefore, the lower color brightness observed in the papaya and tomato treatments may reflect differences in pigment bioavailability and metabolic utilization rather than the complete absence of carotenoid activity.

Comparison with Previous Studies

The findings of this study are consistent with previous reports showing that dietary carotenoid supplementation can improve the color quality of ornamental fish, including goldfish (Khairunnisa et al., 2020; Vega Lestari et al., 2019). Similar results were reported by Ahlam et al. (2019), who found that supplementation with pumpkin and carrot flour improved color intensity in Oranda goldfish. Darsiani et al. (2025) also reported that carrot flour added to commercial feed increased body color brightness in goldfish, although it did not significantly affect growth or survival.

The present study showed a particularly strong treatment effect, as indicated by the high η^2 value ($\eta^2 = 0.894$). This suggests that the experimental treatments explained a large proportion of the variation in color brightness. The stronger response observed in the carrot treatment may be related to the use of a natural flour-based feed formulation, relatively uniform treatment conditions, and controlled rearing management, which may have supported more efficient carotenoid deposition in the fish integument.

The result also supports the findings of Budi (2021), who reported that carrot flour can improve color intensity in ornamental fish. However, the magnitude of color enhancement in the present study appeared higher, possibly due to differences in feed preparation, β-carotene concentration, treatment duration, and fish physiological condition. Similarly, Mia Cindi Audina et al. (2020) reported that tomato extract could enhance fish coloration, but its effectiveness was lower than that of β-carotene-rich sources. This is consistent with the present result, in which the tomato treatment produced lower color brightness than the carrot treatment.

Survival Rate

In addition to color brightness, this study also evaluated fish survival during the rearing period. The survival rate data are presented in Table 2.

Table 2. Survival rate of goldfish in each treatment

Treatment	Initial Number	Surviving Fish	Dead Fish	Survival Rate
P1 (Control)	6	4	2	67%
P2 (Carrot)	6	5	1	83%
P3 (Papaya)	6	5	1	83%
P4 (Tomato)	6	5	1	83%

Based on Table 2, the survival rate was calculated by comparing the number of fish remaining alive at the end of the study with the initial number of fish stocked. The results showed that the treatments supplemented with natural β-carotene sources, namely P2, P3, and P4, had higher survival rates (83%) than the control treatment (67%). This 16% difference indicates a tendency toward improved survival in fish receiving carotenoid-supplemented feed.

The higher survival observed in the β-carotene-supplemented treatments may be related to the physiological role of carotenoids as antioxidant compounds. Carotenoids can contribute to oxidative stress reduction, immune modulation, and improved physiological condition in fish (Nakano and Wiegertjes, 2020; Ahmed et al., 2023).

Ahmed et al. (2023), for example, reported that carotenoid-enriched feed improved pigmentation, β-carotene content, health status, and immune-physiological responses in goldfish. However, because the number of fish in each treatment was relatively small, the survival rate data in the present study should be interpreted descriptively. Further studies with larger sample sizes and appropriate statistical analysis are needed to confirm whether the observed survival difference is significant.

Fish Growth

Fish growth during the study was evaluated based on length gain and weight gain. The growth data are presented in Table 3.

Table 3. Mean length and weight gain of goldfish in each treatment

Treatment	Length Gain (cm)	Weight Gain (g)	Tukey Notation
P1 (Control)	1.12	2.45	a
P2 (Carrot)	1.18	2.60	a
P3 (Papaya)	1.15	2.52	a
P4 (Tomato)	1.14	2.50	a

Note: The same letters indicate no significant difference based on Tukey's HSD test at a 95% confidence level ($p > 0.05$).

As shown in Table 3, length gain and weight gain were relatively similar among treatments and did not differ significantly ($p > 0.05$). This indicates that the addition of natural β-carotene sources to the diet did not significantly affect the morphometric growth of goldfish.

Biologically, this result is reasonable because carotenoids such as β-carotene function primarily as pigment sources and physiological regulators rather than direct growth promoters. Their main roles are associated with pigmentation, antioxidant activity, and immune support (Khairunnisa et al., 2020; Vega Lestari et al., 2019; Nakano and Wiegertjes, 2020). In contrast, fish growth is more strongly influenced by dietary protein, lipid, energy content, feed intake, and nutrient digestibility. Because the basal feed composition in this study was maintained relatively similar across treatments, the absence of significant growth differences indicates that the effect of β-carotene supplementation was more clearly expressed in body color improvement than in growth performance. This interpretation is also consistent with Darsiani et al. (2025), who reported that carrot flour supplementation improved goldfish color brightness but did not significantly affect growth parameters.

Water Quality Conditions

Water quality was monitored during the study to ensure that environmental conditions did not act as a dominant confounding factor. The observed parameters included temperature and pH, as presented in Table 4.

Table 4. Water quality parameters during the study

Treatment	Temperature (°C)	pH
P1 (Control)	29	6.1
P2 (Carrot)	29	6.7
P3 (Papaya)	28	5.7
P4 (Tomato)	29	6.8
Average	28.75	6.3

Based on Table 4, water temperature during the study ranged from 28 to 29°C, while pH ranged from 5.7 to 6.8. The temperature values were within the suitable range for goldfish maintenance, which is generally around 25–30°C (Kadarini et al., 2021; Manullang, 2019). The pH values were mostly within or close to the recommended range for goldfish culture. However, the pH value in P3 (5.7) was slightly below the commonly recommended range of 6.0–8.0. Although this lower pH did not appear to cause a marked reduction in survival or growth in the present study, it should still be considered in future experiments because pH fluctuations can affect fish physiological condition, stress response, and nutrient utilization.

Overall, the relatively stable temperature and pH conditions suggest that the differences observed among treatments were more strongly associated with dietary pigment sources than with environmental variation. This interpretation is supported by the finding that color brightness increased significantly in the carrot treatment, whereas growth remained statistically similar among treatments and survival was relatively stable in the β-carotene-supplemented groups. Stable water quality is particularly important in pigmentation studies because poor environmental conditions may mask or distort the effects of dietary carotenoids on fish coloration.

From a theoretical perspective, the results strengthen the understanding that, in ornamental fish culture, pigment-related nutrients such as carotenoids are more closely associated with aesthetic quality, especially body coloration, than with growth. Growth is primarily influenced by macronutrient composition and energy availability, while survival is strongly affected by environmental stability and physiological condition. From a practical perspective, this study indicates that carrot flour has strong potential as a natural β-carotene source for improving goldfish color brightness, provided that feed formulation and water quality are properly managed.

CONCLUSION

This study demonstrated that the inclusion of natural β-carotene sources in the diet improved the color brightness of goldfish (*Carassius auratus*), with a more evident response observed during the later rearing phase. Among the tested treatments, P2 (carrot) showed the highest effectiveness compared with P3 (papaya), P4 (tomato), and P1 (control), indicating that carrot was the most effective natural β-carotene source for enhancing goldfish pigmentation. Dietary supplementation with natural β-carotene sources did not adversely affect fish growth, as growth performance remained relatively similar across all treatments. This finding suggests that β-carotene primarily contributes to color enhancement without disrupting normal growth processes. In addition, survival rates remained high across treatments, indicating that the use of natural β-carotene sources in the diet is safe for goldfish during the rearing period. Overall, these findings suggest that natural β-carotene supplementation provides a favorable combination of improved color quality, stable growth performance, and high survival. Therefore, carrot can be recommended as an effective and safe natural feed ingredient to enhance the aesthetic quality of goldfish in ornamental fish culture.

RECOMMENDATION

Future studies are recommended to further examine the use of natural β-carotene sources at different concentrations or in combination with other ingredients to determine the most optimal feed formulation for enhancing the color brightness of goldfish. Further research may also involve a longer rearing period and additional observation parameters, such as pigment accumulation in fish skin tissue and physiological responses to dietary carotenoid supplementation.

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