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Potential effects of astaxanthin on the growth performance, survival, and colour brightness of *Channa marulioides* (Bleeker, 1851) in feed domestication

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Abstract

The domestication of native fish species such as *Channa marulioides* requires dietary strategies that replicate natural feeding habits while fulfilling nutritional requirements. This study evaluated the effects of artificial pellets enriched with astaxanthin in combination with different natural feed additives on growth, survival, and pigmentation. Fish were reared for 100 days under four dietary treatments: T1 (maggot), T2 (tubifex), and T3 (dried shrimp), each supplemented with 100 mg/kg astaxanthin in commercial pellets, along with a control group receiving only commercial feed. Diet strongly influenced growth performance, with T3 yielding the best results. Fish in this treatment achieved an average weight gain of 89.76 g, a length increase of 10.15 cm, and a relative length gain of 94.32%. Feed conversion efficiency was also highest in T3 (FCR = 1.33), outperforming the other treatments. Carotenoid accumulation in epidermal scales and tail fins was greatest in T3, with values of 8.51 and 13.6 µg/g, respectively, which corresponded to improved colour brightness as measured by the Modified Toca Colour Finder (m-TCF). Survival exceeded 80% in all groups, with no significant differences observed. These findings suggest that dried shrimp combined with astaxanthin-supplemented pellets represents the most effective feeding strategy to enhance growth and pigmentation, thereby supporting domestication and large-scale aquaculture of *C. marulioides*.

Keywords: Aquaculture, Carotenoid, Feed Formulation, Length Gain, Pigmentation, Weight Gain

1. Introduction

The domestication of freshwater fish species plays a critical role in supporting the sustainability of inland fisheries while contributing to ecological stability and socioeconomic development [1]. Previous studies have stressed the importance of conserving and managing indigenous species in freshwater ecosystems, particularly in response to overfishing and declining environmental carrying capacity, both of which threaten the availability of fish resources [2, 3]. Among native species, *Channa marulioides* is recognised for its high ornamental and economic value, with increasing international demand. It is widely distributed in freshwater systems of Malaysia and Indonesia, especially on Borneo Island, where it inhabits rivers and lakes [4]. The development of reliable domestication and fry-rearing strategies is therefore essential to secure continuous production and reduce reliance on wild capture [5,6].

Feed management represents a fundamental aspect of aquaculture, encompassing feed composition, quality, and feeding regimes [7]. Artificial feeding methods have been established as part of domestication programmes to facilitate the adaptation of wild fish to cultivated environments [8,9]. Integration of commercial feeds with natural dietary sources is particularly important to ensure optimal nutrition, as it influences feed conversion ratio (FCR), growth, and survival [10]. Moreover, as an ornamental fish, *C. marulioides* requires not only growth but also enhanced pigmentation to improve market value. Astaxanthin, a natural C40 carotenoid, is widely applied in aquafeeds to enhance pigmentation, improve reproductive fitness, and support overall culture sustainability

[11,12]. Both synthetic and natural forms of astaxanthin have been shown to significantly enhance fish's colouring and well-being [13].

Alternative animal protein sources such as maggots, tubifex, and dried shrimp represent practical supplements to commercial pellets, offering high protein levels (48–60%) and essential amino acids that support growth and metabolic performance [14–16]. These ingredients are readily available, cost-effective, and tasty, making them promising candidates for feed domestication programmes. However, limited studies have addressed the combined use of astaxanthin-enriched commercial pellets with these supplemental feeds for *C. marulioides*.

The present study was designed to evaluate the effectiveness of incorporating maggots, tubifex, and dried shrimp into astaxanthin-supplemented commercial diets. The outcomes assessed included growth performance, feed efficiency, survival, carotenoid accumulation, and colour brightness measured using the m-TCF scale. Findings from this research are expected to contribute to insights for developing effective feed domestication strategies, ultimately enhancing aquaculture production and reducing dependence on wild stocks of *C. marulioides*.

2. Materials and methods

2.1 Fish rearing

This study was conducted over a 100-day period involving the cultivation of *Channa marulioides* in semi-open rearing ponds, with a 72-hour acclimation period following transit. Each pond measured 100 × 50 × 50 cm and contained 30 cm of freshwater sourced from treated groundwater, which was processed through a recirculating water system for 48 hours prior to use. In this study, water quality was standardised across all treatments as a controlling variable. All tanks were supplied from the same spring source, maintaining a pH of 5–6. Dissolved oxygen levels were kept within 4–5 mg/L using a continuous recirculation system, while temperature was regulated at 25–26 °C by automatic heating–cooling devices. This uniform management ensured comparable environmental conditions among treatments and allowed observed growth differences to be attributed mainly to dietary factors. The experimental fish, *C. marulioides* fingerlings, were selected based on specific criteria: they had a maximum individual weight of 9.5 g and a total length of 10 cm and exhibited size homogeneity exceeding 95%. We maintained a stocking density of 300 individuals per tank (equivalent to 2 individuals per litre) throughout the rearing period. The experiment followed a completely randomised design (CRD) with three replicates, ensuring that each experimental unit had an equal probability of receiving any given treatment, thereby minimising the potential bias in the study.

2.2 Fish Feed

The experimental diets consisted of dried shrimp (protein content 51%), frozen *Tubifex* (protein 50–53%), and maggots (protein 48–52%). In addition, fish were provided with floating commercial pellets (1–2 mm in diameter). According to the manufacturer, the pellets contained 50–52% crude protein, 9% crude fat, 2% crude fibre, ≤15% ash, and ≤11% moisture. The powdered astaxanthin that is used comes from Akanomoto, Japan. Astaxanthin was added to the mixed pellet feed at a dosage of 100 mg/kg of commercial fish feed [17]. The feed was prepared by weighing commercial pellets, dissolving 100 mg of astaxanthin in 100 mL of distilled water, and spraying the solution evenly onto the pellets. The quantity of supplemental feed was subsequently adjusted according to each treatment. Four dietary treatments were formulated to evaluate the effects of different supplemental feeds. Treatment T1 consisted of commercial pellets enriched with astaxanthin and combined with maggots. Treatment T2 used commercial pellets supplemented with astaxanthin and *Tubifex*. Treatment T3 included commercial pellets enriched with astaxanthin together with dried shrimp. The control group received only commercial pellets without astaxanthin or supplemental feed additives. Fish were fed daily at 5% of biomass, consisting of astaxanthin-enriched pellets and supplementary feeds according to treatment. Feeding was conducted three times per day (morning, afternoon, and evening), and feed efficiency was evaluated using the feed conversion ratio FCR following [18].

Feed Conversion (FCR): *feed intake* (*g*)/*fish weight gained* (*g*)

2.3 Growth Performance

Growth rate monitoring was conducted by measuring the mean weight gain, mean length gain, and percentage increase in length of the experimental fish. For each treatment group, individual total length and body weight were recorded using a calibrated measuring board and an analytical balance with 0.01 g precision. Measurements were performed at both the beginning and the end of the rearing period to determine overall growth performance. Fish survival was monitored daily during culture by counting and removing mortalities, with survival expressed as a percentage of the initial stock. This procedure ensured that growth and survival assessments represented the entire culture duration. At the end of the rearing period, growth and survival parameters were calculated using the following equations [18]:

Absolute fish growth (AFG, g) = $Wf - Wi$

Survival rate (SR, %) = $100 \times (Nf / Ni)$

Absolute body length (ABL, cm) = $Lf - Li$

Length growth percentage (LG, %) = $100 \times ((Lf - Li) / Li)$

In these formulas, Wi represents the initial body mass (g), Wf is the final body mass (g), Li is the mean initial body length (cm), Lf is the mean final body length (cm), Ni is the number of fish at the start of the experiment, and Nf is the number of surviving fish recorded at the end of the study. These measurements were applied to quantify biomass accumulation and morphological changes during the culture period.

2.4 Colour Brightness

Body colour brightness was assessed as an indicator of astaxanthin metabolism using the Modified Toca Colour Finder's (m-TCF) method [19]. A five-member panel with normal vision standardises their perceptions before scoring them to minimise bias. Evaluations were conducted every 50 days, and colour brightness was rated on a 1–15 scale, ranging from pale yellow to dark orange. The distribution of scores obtained during the experiment is shown in Figure 1.

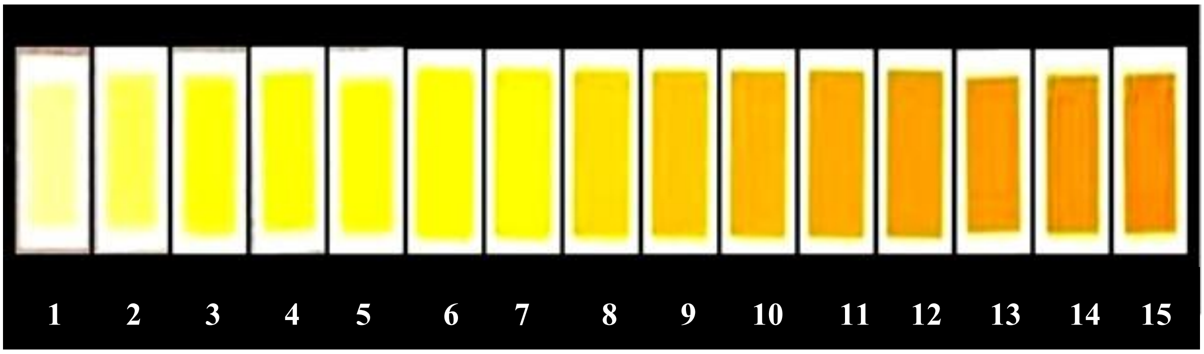

Figure 1 Modified toca colour finder (M-TCF).

The total carotenoid content in scale and tail fin tissues was measured at the start and end of rearing using a spectrophotometer, with pigment extraction performed following [20]. A sample of approximately 2 mg is collected and deposited in a test tube. Subsequently, 5 ml of acetone is added to the test tube, and the mixture is homogenised until complete dissolution. Acetone is then added to a volume of 10 ml, and the mixture is homogenised. The mixture is then allowed to stand overnight at 0°C. Whatman filter paper was utilised to filter the sample liquid, and the resultant solution was analysed with a spectrophotometer at wavelengths of 380, 450, 475, and 500 nm. It is then calculated using the formula [21]:

$$\text{Total carotenoid concentration } (\mu g/g): \left(\frac{Absorbance\ at\ Max\ Wavelength}{0.25\ x\ Sample\ Weight\ (g)}\right) \times 10 \quad (1)$$

2.5 Data Analysis

Statistical analyses were performed on growth, survival, FCR, and carotenoid data. All variables were subjected to one-way analysis of variance (ANOVA). When significant differences were detected ($p < 0.05$), mean comparisons were carried out using Tukey's honestly significant difference (Tukey's HSD) post-hoc test. All analyses were conducted in SPSS Statistics version 23 (IBM Corp., Armonk, NY, USA).

3. Results and discussion

3.1. Growth Performance

Growth performance was assessed by measuring fish weight and length at the start and end of the rearing period. This approach minimises stress during acclimation while ensuring a reliable evaluation. Measurements were taken at fixed intervals, providing a comprehensive assessment of growth and feed conversion efficiency. The results are summarised in Table 1.

Table 1 Performance in terms of growth and feed conversion rate.

Performance	Treatment			
	T3	T2	T1	Control
AFG (g)	89.76 ± 0.23[a]	67.94 ± 1.24[b]	73.93 ± 0.93[b]	55.45 ± 4.64[c]
FCR	1.33 ± 0.38[a]	1.69 ± 1.98[b]	1.78 ± 2.13[b]	2.77 ± 3.81[c]
ABL (cm)	10.15 ± 0.014[a]	5.8 ± 0.023[b]	7.46 ± 0.014[b]	3.62 ± 0.76[c]
LG (%)	94.32 ± 0.012[a]	72.41 ± 7.79[b]	81.2 ± 7.82[b]	47.18 ± 10.20[c]

Remarks: Values are presented as mean ± SEM (n = 3). Different superscript letters (a–c) within a row indicate significant differences among treatments ($p < 0.05$).

This study indicated that diet composition influenced fish growth, with T3 (astaxanthin pellets plus dried shrimp) producing significantly greater length gain than T1, T2, and the control ($p<0.05$). During the cultural period, the More specifically, the length growth percentage was 94.32%, and the length gain was 10.15 cm in T3. The study's findings also indicated that, for 72.41% of the total, the T2 resulted in a 5.8 cm gain in length. Conversely, the T1 produced a 7.46 cm increase in length, or 81.42% of the total. $p>0.05$ indicates that this difference was not statistically significant. When compared to the control treatment, there was a significant difference in the length growth for each treatment that included astaxanthin-containing pellets and different meal combinations. In particular, there was only a 3.62 cm increase in length, or 47.18% of the total length growth. This study indicates that the development rate and length of *C. marulioides* throughout the culture process are affected by the addition of astaxanthin to feed components together with different supplemental feeds. The rate of length development during culture was not substantially affected by the use of feed without astaxanthin or the addition of additional feed.

During the rearing process, fish can adjust to their surroundings by responding to weight gain. According to this study, there were statistically significant differences ($p<0.05$) between the treatments and the control therapy. The influence of different meal combinations on weight growth over the observation period is highlighted by these data. Weight and length had a positive correlation, according to this study, and the T3 showed a significantly faster rate of weight increase ($p<0.05$), or 89.76 g, than the other treatments. Furthermore, a statistically significant difference ($p>0.05$) was not seen between the weight gain of treatment T2 (67.94 grams) and treatment T1 (73.93 grams).

With a statistically significant ($p<0.05$) efficiency value of 1.33, the T3 treatment has the maximum efficacy value, as indicated by the FCR indicator. The FCR values of 1.69 and 1.78 comparing the T2 and T1 treatments showed no significant difference ($p<0.05$). Nevertheless, an FCR score of 2.77 indicated a substantial difference when compared to the control therapy. The results of this investigation indicate that utilising many alternative feed sources in conjunction, with the addition of astaxanthin, may improve the efficiency of *C. marulioides'* feed intake throughout the rearing phase.

The body shape of *C. marulioides*, a freshwater fish, is uniformly flat and continues to the tail. Its growth rate can be calculated using its weight and body length. The reared *C. marulioide*s fish show average growth and have successfully adapted to a controlled environment, as evidenced by the continuous increase in weight and length over the raising process. The current study allegedly explained the length and weight increase as the result of feeding *C. marulioides* protein-rich pellets and additional feed that contains astaxanthin. Astaxanthin exhibits a positive influence on growth performance [22]. In research by [23], it was discovered that feeding astaxanthin to Tiger Oscar fish (*Astronotus ocellatus*) increased their weight and length growth. The findings of this research indicate that incorporating a combination of astaxanthin into pelleted feed could be a feasible strategy for feed adaptation during domestication efforts.

Supplementing the feed is crucial for enhancing the development rate of *C. marulioides* during the raising process. The findings indicated a considerable influence of the supplementary feed on the growth rate of both length and weight in dried shrimp, in comparison to alternative forms of additional feed. The presence of globe cells in shrimp-based feed impacts their growth rates. These globe cells have the potential to enhance the gut performance of *C. striata* [24]. This study demonstrates that the amino acids and proteins present in dried shrimp are rapidly assimilated by *C. marulioides*, contributing to marked increases in body weight and length. In addition to their high protein content, dried shrimp provide a characteristic aroma that stimulates feeding activity, thereby enhancing growth performance [25]. However, other supplemental feeds also contributed to the observed outcomes. Maggots are rich in crude protein (approximately 48–52%) and contain essential amino acids such as lysine and methionine, as well as beneficial fatty acids that support tissue development and energy metabolism. Tubifex, on the other hand, offers a high protein level (50–53%) combined with essential fatty acids and micronutrients that improve digestibility and feeding efficiency. These nutritional properties explain why treatments using maggot (T1) and tubifex (T2) supported growth, although not to the same extent as dried shrimp (T3). Collectively, the results indicate that combining astaxanthin with alternative protein-rich feeds enhanced length and weight gain of *C. marulioides*, improved feed domestication, and ultimately supported better cultivation performance.

3.2. Survival Rate

The survival of *C. marulioides* during the 100-day culture period remained high, with values above 80% across all treatments. Statistical analysis revealed no significant differences among groups ($p > 0.05$), indicating that variations in supplementary feed had little effect on mortality. These findings suggest that stable water quality, controlled rearing conditions, and sufficient nutrition were the primary factors supporting fish viability. Survival was therefore uniform across treatments and not influenced by dietary composition. The data in Table 2 represent the average observed survival value during the rearing period.

Table 2 Survival percentage.

Treatment	Survival Percentage (%)
T3	82 ± 3.98^{a}
T2	85 ± 4.03^{a}
T1	83 ± 3.92^{a}
Control	84 ± 4.04^{a}

Remarks: Values are presented as mean ± SEM (n = 3). Means within a column followed by the same superscript letter are not significantly different according to statistical analysis ($p > 0.05$).

Overall, the results indicate that the survival rate during cultivation is greater than 80%, which is an excellent range for aquaculture endeavours. At 85%, the T2 treatment exhibited the greatest survival value, followed by the T1 treatment at 83% and the control treatment at 84%. The survival percentage with the T3 treatment was 82%. According to the current investigation, the adjusted variables and the intervention-free control treatment do not vary statistically significantly (P>0.05). The data underwent comprehensive statistical analysis to ascertain the variations in treatment throughout each cycle. Studies have indicated that the concurrent application of astaxanthin and feed does not exert a statistically significant effect on the survival rate of *C. marulioides* during the culture phase.

The survival of *C. marulioides* during cultivation was consistently high across all treatments, with values exceeding 80%. This indicates that the nutritional variations of maggots, tubifex, and dried shrimp as supplementary feeds, when combined with astaxanthin, were sufficient to maintain fish health. The absence of significant differences in survival suggests that feeding composition primarily influences growth and colouration rather than mortality. Similar findings have been reported in aquaculture studies, where adequate nutritional content and balanced feed formulations were shown to sustain survival in carnivorous fish [26]. Furthermore, stable water quality and controlled cultural conditions contribute to minimising stress responses, which are known to affect fish metabolism and survival [27, 28]. These results highlight that while dietary treatments enhanced growth and pigmentation, their effect on survival performance was limited, as all groups maintained comparable survival rates.

The ability of new fish species to adapt and thrive in controlled environments is crucial for the successful domestication of indigenous species that have previously adapted to natural habitats. The survival of *C. marulioides* during the culture period was consistently high, with values above 80% across all treatments. The absence of marked differences indicates that variations in supplemental feed had little effect on mortality. Instead, stable water quality, controlled culture conditions, and adequate nutrition were the primary factors contributing to uniform survival among treatments. These results confirm that while dietary treatments influenced growth, their effect on survival was limited. According to [29], fish exhibit a non-specific stress response to adverse environmental stimuli, which can suppress metabolic activity and ultimately increase mortality risk. Maintaining stable environmental conditions not only supports survival but also enhances the overall cultivation performance of *C. marulioides*.

3.3. Colour Brightness

Colour brightness in *C. marulioides* was assessed throughout culture using the m-TCF scale, with gradations from yellow to orange reflecting its natural pigmentation. All panellists were confirmed to have normal vision before assessment. The mean brightness scores for each treatment throughout cultivation are presented in Figure 2.

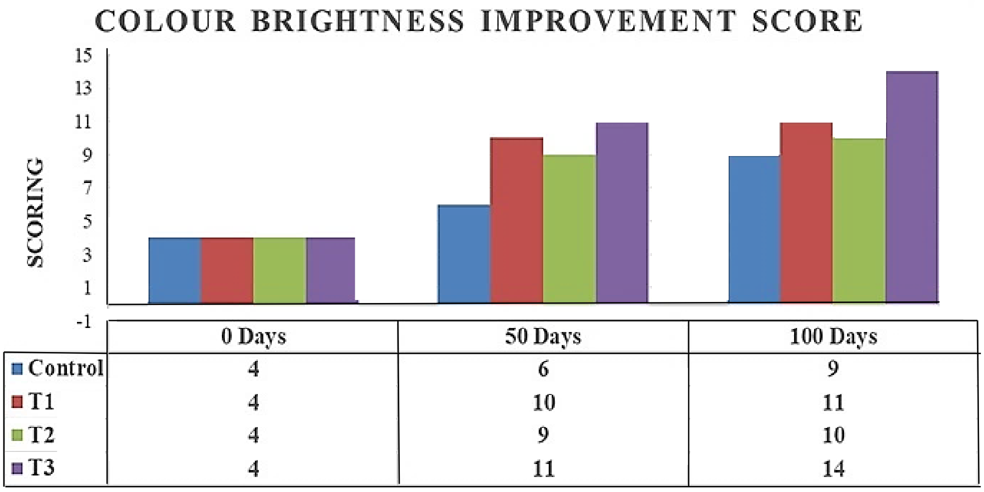

Figure 2 Colour enhancement improvement score.

The interaction between astaxanthin and natural body pigments increased colour brightness throughout the 100-day rearing period. T3 yielded the greatest brightness (14), with T1 and T2 scoring 11 and 10, while the control group showed change at 9. Based on the m-TCF colour assessment, measurement of beta-carotene levels in fish tissues is essential to confirming the observed differences in pigmentation. The average carotenoid concentrations for each treatment are presented in Table 3.

Table 3 Content of carotenoid**s**.

Treatment	Skin Tissue Scales (µg/g)			Tail Fin Scales (µg/g)		
	Pre-Treatment	Post-Treatment	Δ Total Carotenoid	Pre-Treatment	Post-Treatment	Δ Total Carotenoid
Control	5.90	7.84	1.94 ± 0.18^{d}	8.65	14.32	5.67 ± 0.24^{d}
T1	5.83	12.23	6.40 ± 0.16^{b}	9.10	20.41	11.31 ± 0.11^{b}
T2	6.15	10.76	4.61 ± 0.20^{c}	8.88	19.05	10.17 ± 0.13^{c}
T3	5.83	14.34	8.51 ± 3.17^{a}	8.92	22.52	13.60 ± 2.19^{a}

Remarks: Values are presented as mean ± SEM (n = 3). Different superscript letters (a–d) within a column indicate significant differences among treatments ($p < 0.05$).

The results of the carotenoid content observations were consistent with those obtained using m-TCF. T3 treatment resulted in an increase in carotenoid levels in skin scale tissue, with a value of 8.51 µg/g. This difference was statistically significant ($p<0.05$) compared to T1 treatment, which showed an increase of 6.4 µg/g, and T2 treatment, which showed an increase of 4.61 µg/g. The control application, which did not include astaxanthin instruments in fish feed, showed a minimum increase in carotenoid levels of 1.94 µg/g. The tail fin scales exhibited a similar upward trend, with notable variations ($p<0.05$). T3 showed the greatest carotenoid accumulation in tissue samples, reaching 13.6 µg/g, whereas T1 and T2 reached 11.31 and 10.17 µg/g, respectively. The control treatment resulted in a mere 5.67 µg/g rise in carotenoid levels in tail scales. This study demonstrates that there is a positive correlation between the concentration of carotenoids in scales and tail fin tissue and the intensity of colouration in fish.

Examining the intensity of colour is a method used to enhance the quality of C. *marulioides* as a decorative fish product. One potential measure of a fish's capacity to adapt to its diet is the augmentation of its body metabolism, which encompasses the augmentation of pigmentation cells. Specifically, the inclusion of astaxanthin in the feed has been seen to enhance the brightness of colouration. This study observed the fish's capacity to adjust to the offered feed by examining the effects of increasing colour brightness, weight, and length during raising. As a result, the quality of domesticated fish was enhanced. The study conducted by [30] examines the effects of alternative proteins on several aspects of farmed fish, including food, growth, and quality attributes, specifically in relation to skin pigmentation. The inclusion of colour-enhancing compounds in the fish's meal can potentially stimulate an increase in colour pigmentation within the fish's body; alternatively, the fish may be able to sustain the existing colour pigmentation. Astaxanthin is frequently employed as an addition to formulated diets with the aim of augmenting and enhancing the pigmentation of various aquatic animal species, thereby influencing the overall quality and cost of the product [31]. Enhancing the luminosity of colour in decorative fish products can enhance the quality performance of *C. marulioides*, resulting in increased weight and length. This, in turn, leads to higher market pricing and more demand for the product.

The maximum score observed during cultivation in this research was achieved by enhancing colour brightness through the use of pelleted feed containing astaxanthin in conjunction with dried shrimp. According to [32], dried shrimps exhibit elevated concentrations of astaxanthin. The rapid increase in body pigment of *C. marulioides* during rearing can be attributed to the elevated quantities of astaxanthin found in dried shrimps. Furthermore, it is believed that a higher development rate, in comparison to other therapies, leads to increased manifestations of visual colour brightness. Adding maggots and tubifex as supplemental feed resulted in a minor increase in colour brightness, with no significant difference from the control group. This study found that fish that were provided with commercial feed lacking astaxanthin, as well as those given supplementary feed, did not exhibit a statistically significant enhancement in colouration. The commercial feed is believed to possess minimal or negligible levels of astaxanthin, a compound that is significantly lower in comparison to maggots, tubifex, and dry shrimp.

This study suggests the incorporation of astaxanthin pigmentation into the diet of *C. marulioides* fish leads to efficient absorption by the pigment cells in the fish's body, resulting in an augmented yellow colouration throughout the raising process. This phenomenon is evident in the present work, wherein an elevation in carotenoid concentrations is shown during the growing process involving the addition of dry shrimp feed. Notably, the skin and tail scales of the fish exhibit the most substantial rise in carotenoid content. Carotenoids represent a collection of naturally occurring pigments with red, orange, or yellow hues that are commonly observed in aquatic animals [33]. According to [34], the inclusion of carotenoid supplements, such as astaxanthin, in feed has the potential to enhance colouration in aquatic organisms. Pellets supplemented with astaxanthin and dried shrimp promote greater colour intensity and a higher chromatographic density. This is due to the increased digestion and absorption of feed ingredients, resulting in a higher colour intensity of the fish.

Figure 3 Colour enhancement in *C. Marulioides* during cultivation.

Colour brightness increased progressively across treatments during the culture period, as shown in Figure 3. T3 consistently produced the highest brightness scores, followed by T1 and T2, while the control group showed only a minor increase. These results align with carotenoid accumulation in skin and tail tissues (Table 3), indicating that supplementation with dried shrimp enhanced pigmentation more effectively than other treatments. The fish's colouring on the first day corresponds to its original colour at the start of the raising procedure. The results showed that, in the early phases of development, the fish's orange colour did not have a clear and noticeable appearance. After 50 days of raising the fish on astaxanthin, there was a discernible difference in the amount of orange pigmentation that was added to the fish's body. When the 100-day rearing stage is examined in greater detail, results showed the orange colour around the stomach's periphery has increased noticeably. Furthermore, towards the end of the raising phase, the orange tint is seen at the extremity of the fish's tail. That the pelvic fins and tail fins of fish exhibit a greater degree of colour enhancement than other anatomical locations [35].

The inclusion of astaxanthin in both pelleted and supplementary feeds is considered essential for promoting growth and enhancing pigmentation in *C. marulioides*. The results indicate that cultivated *C. marulioides* can effectively adapt to pelleted diets enriched with dehydrated shrimp. Selecting appropriate feed ingredients is critical for improving growth performance, as it reflects the species' natural dietary preferences and ensures adequate nutrition. The early stage of domestication involves modifying commercial pellets with supplementary feeds, a strategy that not only supports adaptation but also improves cultivation performance throughout the rearing process.

4. Conclusions

This study demonstrates that the domestication of *C. marulioides* can be effectively achieved through artificial pellets supplemented with dried shrimp meal and astaxanthin. The proposed diet supported an average weight gain of 89.76 g and a length increase of 10.15 cm, corresponding to a growth rate of 94.32%. Feed efficiency was reflected by a feed conversion ratio of 1.33, while survival exceeded 80%. As an ornamental fish, *C. marulioides* demonstrated efficient pigment uptake, particularly when fed dried shrimp enriched with astaxanthin, which enhanced body colouration. Carotenoid deposition reached 8.51 µg/g in epidermal scales and 13.6 µg/g in tail fins, corresponding to an m-TCF score of 10. Optimising pellet formulations with high astaxanthin content therefore provides a sustainable strategy to improve both growth performance and pigmentation during cultivation.

5. Ethical approval

This research substantially complies with the ethical principles and practice guidelines for research involving animals and humans. This is based on the funding process carried out by the Pontianak State Polytechnic as a higher education organisation with Approval Reference Number: 1102/PL16/KEP/2021, which was approved by the Director of the Pontianak State Polytechnic.

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7. Author Contributions

Rizal, AH.: Conceptualisation, Investigation, Methodology, Supervision, Validation Writing – original draft, Writing – review & editing; Farid, M.: Data curation, Investigation, Software, Visualisation; Susilawati: Funding acquisition, Project administration, Validation; Slamet, T.: Data curation, Formal analysis.

8. Conflicts of Interest

The all authors declare no conflicts of interest regarding the publication and funding of this manuscript.

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