

تأثير الخلطات التجريبية والتجارية على التركيب الكيميائي لأسماك الكارب الشائع *Cyprinus carpio* المستزرعة عند ملوحة 12%

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الملخص

هدفت هذه الدراسة إلى تقييم جودة لحم أسماك الكارب الشائع (*Cyprinus carpio* (Linnaeus, 1758) التي تم تربيتها عند ملوحة قدرها 12% في كلية الهندسة الزراعية في مخبر علوم البحار في الفترة الممتدة (22 مارس 2022 - 26 أيار 2022). تم تقييم أربعة أنواع من الخلطات، حيث صُممت ثلاث خلطات علفية للاستبدال الجزئي لمسحوق السمك بكسبة فول الصويا بمستويات مختلفة، على النحو التالي: الخلطة الأولى (T1) احتوت على 40 غ من وجبة فول الصويا، تلتها الخلطة الثانية (T2) بـ 50 غ من كسبة فول الصويا، والخلطة الثالثة (T3) بـ 60 جم من كسبة فول الصويا دون إضافة مسحوق السمك، وجميع هذه العلائق احتوت على بروتين إجمالي بنسبة 35.75%. بينما كانت الخلطة الرابعة (T4) خلطة تجارية تحتوي على 34% بروتين مستخدمة في مزارع الأسماك في سوريا، واستخدمت كشاهد.

كما هدفت هذه الدراسة أيضاً إلى تحليل التركيب الكيميائي للحم، بما في ذلك التركيب الدهني (الأحماض الدهنية) في أسماك الكارب. حيث بلغت نسبة الرطوبة في لحوم الأسماك المغذاة على الخلطات T1, T2, T3 و T4 حوالي 77.24±2.59% و 78.13 ±1.82%، 79.56±1.94%، 79.47±0.75% على التوالي. بينما بلغت نسبة البروتين 18.89%، 19.88%، 19.44% و 19.1% في علائق T1, T2, T3 و T4 على التوالي. أما بالنسبة لنسبة الدهون، فكانت القيم 2.77%، 2.94%، 2.06%، و 2.5% في الخلطات T1, T2, T3 و T4 على التوالي.

تميزت الخلطة T2 بتركيز استثنائي مرتفع من حمض الأوليك C18:1 57.8%. على النقيض من ذلك، كان هناك انخفاض واضح لعدة أحماض دهنية متعددة عديمة التشعب (PUFAs) الرئيسية من T1 إلى T4. على وجه التحديد، انخفض كل من حمض اللينوليك (6-ω C18:2) وحمض ألفا-لينوليك (3-ω C18:3) بشكل تدريجي، مع الانخفاض الأكثر وضوحاً في حمض الدوكوساهيكسانويك (3-ω C22:6 (DHA))، والذي انخفض من 3.25% في T1 إلى 1.70% في T4.

الكلمات المفتاحية: *Cyprinus carpio*، التركيب الكيميائي، الأحماض الدهنية.

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قبل للنشر بتاريخ: 2026/4/6

ورد للنشر بتاريخ: 2026/1/13

Effect of Experimental and Commercial Diets on the Chemical Composition of Common Carp (*Cyprinus carpio*) Cultured at 12‰ Salinity

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Abstract

The purpose of this study was to assess the meat quality of common carp (*Cyprinus carpio* L. 1758), which were raised at 12‰ salinity. During the research period (22 March-26May2022). Four diets were evaluated in this study: The three diets were designed to partially replace of fish meal by soybean meal at different levels, as follows: The first diet was T1 (soybean meal 40g), followed by diet T2 (soybean meal 50g), and the third diet (soybean meal 60 g without adding fishmeal), all of which had a total protein of 35.75%. The fourth diet was a commercial feed (34% protein) used in fish farms in Syria and designed as the control.

This study also aimed to analyze the chemical composition of the meat including the fatty acid profile of carp lipids. The percentages of moisture in diets T1, T2, T3 and T4 were 77.24%±2.59, 78.13%±1.82, 79.56%±1.94 and 79.47±0.75 respectively, While the percentage of protein was 18.89, 19.88, 19.44 and 19.12% in T1, T2, T3 and T4 diets respectively. As for fat percentage, the values were 2.77, 2.94, 2.06 and 2.52 in T1, T2, T3 and T4 diets respectively. The results showed that the three diets showed significant differences among them.

The diet T2 was characterized by an exceptionally high concentration of oleic acid (C18:1; 57.8%). Conversely, a clear downward trend was evident for several key polyunsaturated fatty acids (PUFAs) from T1 to T4. Specifically, linoleic acid (C18:2 ω-6) and α-linolenic acid (C18:3 ω-3) progressively decreased, with the most pronounced reduction in docosahexaenoic acid (DHA; C22:6 ω-3), which fell from 3.25% in T1 to 1.70% in T4.

Key words: *Cyprinus carpio*, chemical composition, fatty acid composition.

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1-Introduction:

Aquaculture plays a significant role in food needs of an increasing population. Protein production from aquaculture is much more efficient than other protein producing animal husbandry systems (FAO, 2022). Beyond its pivotal contribution to food security, the sector stimulates economic development through generation employment, the advancement of rural communities, and the mitigation of overfishing, thereby aiding in the conservation of marine ecosystems (Garg and Bhatnagar, 2000). Globally, marine fish production constitutes approximately 50% of total aquatic output, with freshwater fish contributing another 38%; carp alone represents 11% of this freshwater production, yielding an annual output of 0.7 million metric tons (FAO, 2024).

In 2022, global fisheries and aquaculture production reached a record high of 223.2 million tons, including 185.4 million tons from aquaculture and 37.8 million tons from algae (FAO, 2024).

The nutritional value of fish is established by its chemical composition, which is primarily defined by its proximate analysis of water, lipid, protein, and ash content. Fish serves as a valuable low-energy-density food source, notable for its high concentrations of polyunsaturated fatty acids (PUFAs) and characteristic long muscle fibers (Kandemir and Polat, 2007). The specific fatty acid composition, however, exhibits significant interspecies variation, largely attributable to differences in native water environments (Connor, 2000). Among these lipids, omega-3 long-chain polyunsaturated fatty acids (n-3 LC-PUFAs), particularly eicosapentaenoic acid (EPA; 20:5n-3) and docosahexaenoic acid (DHA; 22:6n-3), are critical. As essential structural components of cell membranes, these LC-PUFAs are integral to somatic growth, cognitive functions, and may even modulate behavior in vertebrates, including fish (Salin *et al.*, 2021; Tocher, 2010; Z'avorka *et al.*, 2021).

The common carp, *Cyprinus carpio* (Linnaeus, 1758), is a cyprinid fish that has achieved a nearly global distribution. As a member of Cyprinidae—the most species family of freshwater fishes—its success is largely attributable to deliberate anthropogenic introductions, making it the third most frequently introduced species worldwide (Parkos & Wahl, 2014). This invasive potential is underpinned by a high degree of ecological

plasticity. While its native habitat consists of freshwater systems like rivers, lakes, and ponds, the species also demonstrates a tolerance for brackish environments (Barus *et al.*, 2001). This broad adaptability, combined with its established importance in Asia and some European countries, positions *C. carpio* as a highly viable candidate for commercial aquaculture (Rahman *et al.*, 2015)

C. carpio is the predominant species in freshwater aquaculture in Syria, a status primarily attributable to consumer traditions and consistent market demand (Cardia and Lovatelli, 2007). The sector is further influenced by significant socio-economic drivers, including rapid human population growth and an escalating demand for affordable, low-footprint animal protein (Ahmed and Thompson, 2019; Aubin *et al.*, 2021; Campanati *et al.*, 2022). The fatty acid profile of common carp is influenced by extrinsic factors such as diet and environment, typically comprising a mixture of saturated, monounsaturated, and polyunsaturated fatty acids. Among these, omega-3 long-chain polyunsaturated fatty acids (n-3 LC-PUFA), particularly docosahexaenoic acid (DHA), are crucial for human health and can be obtained through dietary consumption of such fish. In general, the tissue fatty acid composition of carp is largely dictated by its dietary intake. For instance, carp fed diets enriched in C18 polyunsaturated fatty acids exhibit elevated levels of these fatty acids in their tissues. Furthermore, carp possess the physiological capacity to synthesize long-chain n-3 polyunsaturated fatty acids from shorter-chain precursors, such as converting alpha-linolenic acid (ALA) into eicosapentaenoic acid (EPA) (Ahmed and Dimovska, 2021).

The sustainability and expansion of aquaculture in Syria are constrained by the high cost of feed ingredients, most notably fish meal, which is entirely imported and not produced domestically. Consequently, a primary objective of this research is to formulate cost-effective diets for common carp through the partial substitution of fish meal with locally available alternatives, such as soybean meal. This study will systematically evaluate the impact of these dietary formulations on the chemical composition and growth performance of the fish. In parallel, this investigation seeks to assess the viability of culturing common carp in brackish water estuaries, with the aim of developing novel fisheries to enhance national food security.

The experimental diets will be benchmarked against a control diet that replicates the standard; low-cost commercial feeds used by local farms. The overarching research goal is to strike an optimal balance between economic feasibility and nutritional quality. While reducing fish meal inclusion is critical for cost reduction, its presence in moderated quantities is vital, as it supplies essential amino acids and other nutrients crucial for maximizing somatic growth and enhancing the final product's nutritional profile for human consumption.

2-Material and Methods:

2-1 Experimental Diet Design:

The present study constructed a series of four treatments to elucidate the impact of experimental and commercial diets (Tables 1-2) on the chemical composition of Common Carp. The experimental treatments (T1, T2, T3) were designed with incremental replacement rates: T1 (40g soybean meal: 20g fishmeal), T2 (50g soybean meal: 10g fishmeal), T3 (60g soybean meal, devoid of fishmeal) and the fourth commercial control diet (T4) with a 34% protein content.

This specific control formulation was chosen as it reflects the prevailing commercial diet in Syrian fish farms, thereby ensuring the experimental findings have direct practical applicability. Due to its lack of commercial relevance, a diet consisting exclusively of fishmeal was not considered as viable control.

Table (1): Chemical composition (The percentage %) of Diets (T1-T3)

The contents	T1	T2	T3
Fishmeal	12.60%	6.3%	-
Soybean meal	18%	22.5%	27%
Bran meal	2.25%	2.55%	3%
Cornmeal	1.9%	1.4%	1%
Methionine	0.25%	3%	4%

Lysine	0.75%	-	% 0.75
Total protein	35.75%	35.75%	35.75%

Table (2): Chemical composition of commercial diet T4 (Control)

The contents	Weight (g)
Soybean meal	45
Cotton meal	13
Poultry Slaughterhouse waste	25
Bran meal	10
Cornmeal	2
Dicalcium phosphate	1.5
Colin chloride	0.5
Methionine	0.5
Minerals	1
Vitamins	1.5
Total	100
Supplements	
Antioxidants	1.5g/100g
Antifungals	50g/100g

2-2 Experimental design:

Ninety juvenile fish were acquired from the Al-Sen Research Center (General Commission for Fisheries Resources and Aquatic Creatures) and immediately relocated to the Marine Science Laboratory, Faculty of Agriculture, Latakia University. The fish were maintained for a one-week recovery period in a large holding tank. During this interval, they were fed the aforementioned diets twice daily at a rate equivalent to 5% of their total body weight. To maintain optimal water quality, continuous aeration was provided, and a 50% water renewal with fresh water was performed daily to prevent the accumulation of nitrogenous wastes and mitigate stress. Water quality parameters (pH, DO, temperature) were

measured daily using a WTW-Multi34DI meter (probes: PDO-408, PCT-407), adhering to standard protocols (APHA, 1988).

2-3 Preparing brine solution:

A preliminary trial was conducted to determine the optimal salinity for rearing juveniles. Brine solutions were prepared by dissolving commercial-grade sodium chloride (NaCl) in freshwater. This approach was selected over the use of natural seawater, as it is a common practice in the husbandry of this species (Tsuzuki *et al.*, 2000). For the preliminary assessment, juveniles were reared under laboratory conditions at target salinities of 0.5‰, 3‰, 6‰, 9‰, and 12‰ to evaluate the effects on growth and survival. The salinity was incrementally increased every 48 hours until the target levels were reached. Results from this trial indicated that a salinity of 12‰ yielded the highest growth performance, with a maximum Specific Growth Rate (SGR) of 0.82 and a Daily Growth Rate (DGR) of 0.67. The experimental system consisted of 12 glass containers (40*50*70cm), housing 10 fish each. All salinity levels were prepared and monitored using a refractometer to ensure accuracy.

2-4 Chemical Composition Analysis:

-Proximate Analysis:

The proximate composition of the fish samples was analyzed to determine the content of moisture, ash, crude protein, and crude fat. All procedures followed the standard protocols outlined by the Association of Official Analytical Chemists (AOAC, 2004). These analyses were carried out at the laboratories of the Faculty of Agriculture, Latakia University.

-Fatty Acid Methyl Ester (FAME) Analysis:

Fatty acid analysis was performed at the National Commission for Biotechnology, Damascus, Syria. Lipid extracts were converted to fatty acid methyl esters (FAMES) prior

to analysis. The FAMES were separated and quantified using a Gas Chromatograph (GC) equipped with a flame ionization detector (FID) and a split/splitless injector. The chromatographic conditions were programmed as follows:

Column Temperature: 185°C (isothermal)

Injector and Detector Temperatures: 250°C

Split Ratio: 1:100

Injection Volume: 1 µL

Carrier Gas: Helium, at a constant flow rate of 1.0 mL/min

2-5 Data analysis:

Statistical analysis was performed using a one-way analysis of variance (ANOVA) (Weissgerber *et al.*, 2018) with SPSS software (version 16.0). Results are expressed as mean ± standard error of the mean with the levels of significance at 0.05.

3-Results and Discussions:

3-1 Growth Performance of *Cyprinus carpio*:

The growth performance results indicated that Diet T2, formulated with 50g soybean meal and 10g fishmeal, yielded the most lucrative outcomes. Fish fed this diet exhibited the highest weight gain (4.55 g) and a superior specific growth rate (SGR) of 2.02 %/day. Furthermore, Diet T2 demonstrated the most efficient feed utilization, with a feed conversion ratio (FCR) of 1.73. The generally low FCR values observed across all dietary treatments can be attributed to the high growth rates, the nutritional quality of the diets, and good feed palatability, as improved feed efficiency is expected under such conditions (Masser, 2002).

Zhang and Li (2022) have demonstrated that a dietary inclusion level of 30% FSBM, replacing an equivalent proportion of FM protein, was most effective in promoting growth in *C. carpio*. This led to significantly superior weight gain and specific growth rate (SGR), and a more favorable feed conversion ratio (FCR) relative to the control group. This

improved performance was mechanistically linked to the fermentation of the soybean meal, a process that mitigated anti-nutritional factors by reducing trypsin inhibitor activity and concurrently enhanced intestinal morphology, which in turn promoted superior nutrient assimilation.

Similarly, a study by Ahmed and Garcia (2024) confirmed the feasibility of balancing economic sustainability with growth efficiency in rainbow trout aquaculture. This balance can be achieved by determining the optimal replacement level of fish meal (FM) with soybean meal (SBM). The researchers hypothesized that a strategic partial replacement would create a synergistic effect, whereby fish meal compensates for the amino acid deficiencies inherent in soybean meal. This, in turn, would lead to enhanced protein utilization and promote growth to a level that surpasses the anticipated effects of each component individually.

Furthermore, the final weight and weight gain of T4 (17.64g and 3.22g, respectively) were slightly higher than those of the control group (17.53g and 3.01g), both groups shared an identical FCR of 1.95. This indicates that despite a marginally better absolute weight gain in T4, the overall efficiency of converting feed into biomass was the same for both T1 and T4. This suggests that the modification in the T4 diet did not confer a significant advantage over the control diet in terms of feed utilization efficiency.

This suboptimal performance was attributed to the fact that the feed was a commercial formulation containing poultry by-product meal (PBM). This observation is corroborated by Al-Masri and Lee (2024), who focused on the practical aspects of formulating commercial feeds. It found that a 40% Poultry by-product meal inclusion level led to a 15% reduction in voluntary feed intake compared to an FM control. Histological analysis of the carp's intestine revealed shorter villi and signs of inflammation in the PBM-fed groups. The researchers concluded that reduced palatability, combined with negative impacts on gut health and nutrient absorption, synergistically contributed to the observed growth retardation.

Table (3): Growth performance (weight in g) of *C. carpio* fed different experimental diets.

	T1	T2	T3	T4
First weight	14.52±0.57	17.81±0.06	15.48±0.01	13.42±0.64
Final weight	17.53±0.02	22.36±0.13	18.06±0.21	17.64±0.07
weight Gain	3.01	4.55	2.58	3.22
Daily Growth Rate	0.03	0.05	0.03	0.03
specific growth rate	1.44	2.02	1.13	1.51
feed conversion ratio	1.95	1.73	2.23	1.95

3-2 Chemical composition of carp meat:

The moisture content decreased from a high of 79.56% in the T3 diet (soybean meal 60g, no fishmeal) to a low of 77.24% in the T1 diet (soybean meal 40g, fishmeal 20g). However, statistical analysis revealed no significant differences ($p > 0.05$) in moisture content among any of the dietary treatments (T1, T2, T3, and T4) (Table 4).

The observed values arrangement with the typical composition of fish muscle, where moisture and lipid content are often inversely related. As reported by Luo *et al.* (2013), increased fat accumulation in fish tissue often occurs at the expense of moisture.

Analysis of the proximate composition revealed significant differences ($p < 0.01$) in the crude protein content of carp muscle across the experimental diets. Fish receiving Diet T2 (soybean meal 50g: fishmeal 10g) exhibited the highest protein concentration at 19.88%, significantly surpassing the T1 group (18.89%). The observed differences can be primarily attributed to the nutritional composition of the test diets, as the protein source and level are known to directly affect tissue deposition. Although other factors, such as endogenous enzymatic degradation (proteolysis) or potential nitrogen volatilization during sample processing, can cause minor variations, their impact would be consistent across all groups and thus unlikely to account for the significant differences found. The variability in muscle

protein is a common phenomenon in aquaculture research; for instance, Ljubojevic et al. (2013) reported similar fluctuations in common carp reared in natural waters, highlighting the influence of both diet and environmental factors on fish body composition.

The highest fat content was observed in the T2 treatment group (2.94%), while the lowest was recorded in the T3 group (2.06%). Variations in fat content within the same fish species can be attributed to the heterogeneous distribution of fat in muscle tissue (Steffens, 2016).

The T2 diet's superiority in promoting growth is biochemically mirrored in a higher quality meat. The fish reared on this diet successfully converted their feed into valuable protein and muscle tissue, as well as essential energy reserves (fat). In contrast, the T4 diet, due to its contained poultry by-product meal, resulted in a lower-quality final product. The higher moisture and lower protein/fat content suggest that the dietary formulation was less efficient at supporting nutrient deposition. This is attributed to the potential negative effects of PBM on gut health and nutrient absorption, ultimately affecting the fish's ability to build tissue effectively.

Table (4): Body composition of *C. carpio* under the (DIETS).

Diets	T1(%)	T2(%)	T3(%)	T4(%)
Moisture	77.24±2.59	78.13±1.82	79.56±1.94	79.47±0.75
Crude protein	18.89±1.25	19.88±1.15	19.44±1.46	19.12±1.63
Fats	2.77±1.05	2.94±0.79	2.06±0.16	2.52±0.84
Ash	1.49±0.44	1.85±0.20	1.38±0.34	1.72±0.47

Huang *et al.* (2023) and Li *et al.* (2023) reaffirmed that SBM can be incorporated into carp diets at substantial levels. The general consensus is that up to 40-50% of fishmeal protein can be replaced by SBM without significant adverse effects on growth performance, feed intake, or Feed Conversion Ratio (FCR); provided the diet is properly balanced.

Analysis revealed significant variation in ash content among the dietary treatments, with the highest concentration recorded in the T2 group (1.85%) and the lowest in the T3 group (1.38%). The ash proportion within fish tissue is known to be governed by a complex interplay of factors. These include nutritional aspects such as feed composition and metabolism (Tokur *et al.*, 2006), alongside intrinsic biological factors (e.g., size, age, gender) and extrinsic environmental variables (e.g., season, geographic location, habitat conditions) (Hindi, 1986). The ash content observed in the current study corroborates existing literature; it is comparable to the 1.3% reported for *C. carpio* from natural habitats (Mehdi *et al.*, 2006). Similarly, our findings are in agreement with Salih and Al-Habib (2013), who recorded low ash percentages (1.104%, 1.19%, 1.074%, and 1.059%) in species including *Barbus belayewi* and *Barbus xanthopterus*.

3-3-Fatty acid profile of *C. carpio* :

Analysis of the fatty acid profiles revealed significant compositional differences among the four dietary treatments (T1-T4) table (5). The most prominent distinction was observed in the monounsaturated fatty acid (MUFA) fraction, where treatment T2 was characterized by an exceptionally high concentration of oleic acid (C18:1; 57.8%), substantially elevating its total MUFA content compared to the other treatments. Conversely, a clear downward trend was evident for several key polyunsaturated fatty acids (PUFAs) from T1 to T4. Specifically, linoleic acid (C18:2 ω -6) and α -linolenic acid (C18:3 ω -3) progressively decreased, with the most pronounced reduction in Docosahexaenoic acid (DHA; C22:6 ω -3), which fell from 3.25% in T1 to 1.70% in T4. The saturated fatty acid (SFA) profile also shifted, with palmitic acid (C16:0) showing a steady increase from T1 to T4, while behenic acid (C22:0) demonstrated a corresponding decrease. Treatment T4 was further distinguished by the lowest levels of most PUFAs and the presence of palmitoleic acid (C16:1), which was absent in the other diets.

The prevalence of oleic acid was the primary determinant of the total MUFA content, and its concentration is consistent with values previously reported for other freshwater fish (Hadjinikolova, 2004; Guler *et al.*, 2008). In contrast, considerably lower values were

observed for pentadecanoic acid (C15:0), at 0.097%, 0.119%, 0.055% and 0.093 for diets T1, T2, T3 and T4 respectively.

Table (5): Fatty acids composition of *C. carpio*.

Diets	T1(%)	T2(%)	T3(%)	T4(%)
C 12:0	0.045±0.02	0.679± 0.01	0.173± 0.06	1.6± 0.05
C 14:0	0.679± 0.03	0.645± 0.39	0.595± 1.56	1.006± 0.38
C 15:0	0.097± 0.55	0.119± 0.70	0.055± 0.92	0.093± 0.05
C 16:0	13.467±0.04	15.577±0.81	17.266± 1.19	18.074± 0.98
C 16:1	-	-	-	0.18±0.39
C 17:0	0.629±0.03	0.333±0.10	0.64± 0.38	0.247±1.22
C 17:1	0.242±0.88	0.2± 1.42	0.092±0.07	0.267±0.36
C 18:0	6.805±1.59	6.622±0.17	7.283±0.98	5.498±0.30
C 18:1	44.034± 0.17	57.831± 0.02	47.781± 0.06	46.608± 0.02
C 18:2 (ω- 6)	22.036±0.39	18.75±0.01	17.265 ± 0.02	12.178± 0.05
C 18:3 (ω- 6)	0.1±0.96	-	-	-
C 18:3 (ω- 3)	3.296±0.12	2.801±0.56	2.603± 0.12	0.466±0.32
C 20:0	0.123±0.25	0.345±0.58	0.491±0.02	-
C 22:0	0.704±0.01	0.571±0.02	0.464±0.03	0.063±0.56
ARA	0.871±0.054	1.033±0.26	0.294±0.87	1.126±0.13
EPA	0.254±0.17	0.195±0.07	0.185±0.01	0.213±0.02
DPA	1.020±0.96	1.8±0.24	1.01±0.47	0.98±0.36
DHA	3.251±1.23	2.489± 1.02	2.01±0.01	1.698±0.02

A primary distinction between the two treatment groups was the markedly elevated saturated fatty acid (SFA) content in fish fed the poultry by-product meal (PBM) diet (T4). This was most evident in the significantly higher concentrations of key SFAs: lauric acid (C12:0) was exceptionally high in the T4 group (1.6±0.05%) compared to T2 group (0.679±0.01%), while palmitic acid (C16:0) was also substantially elevated (18.074±0.98% in T4 vs. 15.577±0.81% in T2). This SFA profile is characteristic by animal-derived ingredients and is considered suboptimal for aquaculture (Li & Wang,

2024). From a nutritional standpoint, such high levels of SFAs, particularly lauric and myristic acids, can impair digestibility in fish and are associated with adverse health implications for human consumers. Consequently, the lower SFA profile achieved with the soybean meal diet (T2) represents a significant advantage in terms of both fish physiology and final product quality.

The T2 diet, formulated with soybean meal, demonstrated a significant nutritional advantage over T4 diet by providing a markedly superior profile of essential polyunsaturated fatty acids (PUFAs). This was particularly evident in the ω -3 series, where the T2 group exhibited a dramatically higher concentration of α -linolenic acid (C18:3 ω -3), containing over six times the amount ($2.801 \pm 0.56\%$) found in T4 group ($0.466 \pm 0.32\%$). This disparity is attributed to the intrinsic richness of soybean meal in this vital fatty acid precursor, a quality notably absent in poultry by-product meal (PBM) (Chen & Liu, 2021). Furthermore, this advantage extended to the most valuable long-chain ω -3 fatty acids; T2 group showed significantly higher retention of docosahexaenoic acid (DHA) ($2.489 \pm 1.02\%$) compared to T4 group ($1.698 \pm 0.02\%$). DHA is paramount for neural development and overall fish health, and its elevated presence enhances the nutritional value of the final product for consumers. While T2 group also contained a higher level of the essential ω -6 fatty acid linoleic acid (C18:2 ω -6) ($18.75 \pm 0.01\%$ vs. $12.178 \pm 0.05\%$ in T4), the overall effect was a much more favorable ω -6 to ω -3 ratio, which is strongly linked to improved fish health and product quality (Chen & Liu, 2021). In contrast, the severe ω -3 deficiency observed in T4 group highlights a significant nutritional limitation of PBM-based diets, which would necessitate supplementary fish oil in practical formulations to meet the species' physiological requirements and produce a marketable product.

Arts *et al.* (2001) established that long-chain omega-3 fatty acids (LC-PUFAs) with 20 and 22 carbon atoms possess superior nutritional value compared to their C18 counterparts. The prevalence of these fatty acids, particularly eicosapentaenoic acid (EPA; C20:5 ω -3) and docosahexaenoic acid (DHA; C22:6 ω -3), is a primary determinant of the dietary ω -6: ω -3 ratio. Furthermore, the same authors caution that while this ratio is a critical indicator of nutritional quality, it must be evaluated in conjunction with the absolute concentrations of the individual polyunsaturated fatty acids to provide a complete assessment.

The high concentration of DHA and EPA in Diet 1 is a direct result of its high fishmeal content, as fishmeal is one of the few natural ingredients rich in eicosapentaenoic acid (EPA; C20:5 ω -3) and docosahexaenoic acid (DHA; C22:6 ω -3). Carp, like most vertebrates, have a limited ability to synthesize these LC-PUFAs from shorter-chain precursors. These fatty acids are vital not only for the fish's immune response, stress tolerance, and reproductive health but also for enhancing the nutritional quality of the final fillet for human consumption (Zhang *et al.*, 2024).

Conclusions:

The present study demonstrates that the strategic substitution of fishmeal with soybean meal (SBM) in T2 diet is a superior approach for common carp farming. This formulation not only enhances sustainability but also significantly improves production efficiency and product quality. This is evidenced by a more favorable protein-to-lipid ratio and a healthier fatty acid profile. In contrast, T4 diet, is a suboptimal alternative due to its reliance on poultry by-product meal (PBM), which compromises the final product quality with an elevated saturated fat content and reduced essential omega-3 fatty acids. Therefore, the adoption of SBM represents a more effective strategy for achieving both economic viability and ecological responsibility in aquaculture.

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