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Review on the fatty acid profile and free fatty acid of common carp (*Cyprinus carpio*)

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SUMMARY

Carp or ponty in Hungarian, is considered commercial freshwater fish, which is an adaptable species in both wild and cultured conditions. Carp has high nutritional value content, favorable taste, it is rich in protein, and low in saturated fat. The nutritional content in fish is composed of many chemical constituents and influenced by many factors. One of the components that its content may be different due to internal and external factors is fatty acids, which may vary depending on endogenous and exogenous factors. The endogenous or internal factors include the genetic, size, sexual maturity, and life cycle phase. While microclimate, water quality, quality of food or diet habit, and the amount of available food or starvation are considered as exogenous or environmental factors. Freshwater fish has the ability to convert essential fatty acid into long chain polyunsaturated fatty acid like AA, EPA, and DHA. Most results showed that palmitic acid and oleic acid were the dominant SFA and MUFA in carp both for wild and farmed carp in all seasons. The PUFA for wild carp was mainly dominated by DHA, while on farmed carp by LA. It confirmed that high LA content in farmed carp was related to the diet habit. The amount of lipid and FA were changed in line with the season. Even the statistical analysis showed no significant difference, but some studies showed a contrasting result. Moreover, most obtained results acknowledged that FA tends to decrease during the spawning period. The amount and composition of FA were affected by the total lipid content. The lipid must be broken down into simpler compounds such as FA or FFA for the metabolism of fish. The result of metabolism then transported into the utilising tissue and used as energy.

Keywords: *common carp; fatty acid; PUFA*

INTRODUCTION

According to (Eurostat, 2023), the EU total aquaculture production in 2021 was worth 4.2 billion euro or estimated to be 1.1 million tons of aquatic organisms. In Hungary itself, the total market size was 19.647 tons in 2021. The fish species which widespread cultured in Hungary are Common carp (*Cyprinus carpio*) which produced 13.294 tons of carp (FEAP, 2022). Carp or called ponty in Hungarian, is considered commercial freshwater fish, which is adaptable species in both wild and cultured conditions. It is indigenous to Asia and was introduced to Europe and North America in the 1800s. Since 1964, Hungary started to develop the breed strains of common carp from the most significant Hungarian fish farm, and it is the only domesticated species of Hungarian fish fauna (Bakos & Gorda, 2001).

In Europe, carp is not only for consumption but also can be used as the recreational fisheries, ornamental fish, and water quality control. The fish production represents only a minor part of the Hungarian economy, but the Hungarian aquaculture has a world-wide reputation in carp breeding, water management, nature conservation, water-related tourism, and rural development. About 74 percent of total fish production in Hungary is dominated by common carp, and approximately around 25.000 ha of production area in Hungary was using extensive freshwater aquaculture for rearing the common carp (Stündl et al., 2014).

There are limited studies regarding the meat quality of common carp. The primary objective of this study was to review the meat quality, especially on the fatty acid profile and free fatty acid on common carp. As an economically important freshwater commodities, carp provide abundant unsaturated fatty acid and protein. Some type of unsaturated fatty acid plays a role for human prevention of disease such as cardiovascular disease (Hu et al., 2021). For the fish itself, fatty acid works as as an energy source for growth, metabolism, and reproduction. Also, It was expected to contribute to enhancing literature about the chemical composition on the meat quality of common carp. The result of this analysis was essential because it could provide useful information concerning the nutritional value of common carp.

RESULTS AND DISCUSSION

Common carp

Common carp (*Cyprinus carpio*) belong to the Family *Cyprinidae* is one of the oldest cultured and most domesticated fish in the world. The carp have spread in the west and east direction in ancient times. The carp that migrated in east direction was reached China, and its migration in west direction was reached Black and Aral Seas, where it ended arriving in the Danube River system some 10.000 years ago. Around that century, the Roman might also transport the carp into Italy and stocked it into the holding ponds. The initial distribution of carp in Europe took place between the seventh and thirteenth centuries, and it continued expanding and widespread (Wohlfarth, 1995).

From time to time, increasing demand for fish consumption and limited resources of marine fish causing the expansion of freshwater aquaculture.

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Freshwater fish is considered healthy food due to its high protein content with a balanced amino acid profile, moderate amounts of healthy lipids, and less n-3 Polyunsaturated Fatty Acid PUFA compared to marine fish. It also contains a good source of protein and essential minerals. The protein content in common carp ranged from 47.3–76.4% of dry weight, and the fatty acid in carp mainly dominated by Eicosapentaenoic Acid EPA and Docosahexaenoic Acid DHA (Dong et al., 2017).

The lipid and protein content on fish may vary depending on the feeding habit, size, age, reproductive status, geographic location, season, and temperature. In general terms, it is called an endogenous and exogenous factor. The endogenous or internal factors including the genetic, size, sexual maturity, and life cycle phase. While microclimate, water quality, quality of food or diet habit, and amount of available food or starvation are considered as exogenous or environmental factors. Moreover, for consumption purposes, the other factor such as the part of the flesh, preparation, and processing also may influence the chemical composition of the meat (Marković et al., 2016; Mráz & Pickova, 2011; Yeganeh et al., 2012).

The chemical composition of wild fish is strongly influenced by the environmental conditions, while in the farmed fish, the feeding using an artificial diet produces a specific nutrient on the flesh compositions. The lipid content on farmed fish is stabler compared to the wild fish. It is also known that the acceptability of wild fish is better than the farmed fish, but it is not impossible to produce farmed fish, which is equivalent or superior in terms of nutritional values (Yeganeh et al., 2012). In nature, the original food source for the omnivorous fish like carp is phytoplankton and zooplankton, which rich in proteins, fats, oligopeptides, vitamins, free fatty acids, and essential fatty acids (Ljubojević et al., 2015). Previous study showed a close correlation between phytoplankton and zooplankton in affecting the PUFA of carp (Trenovszki et al., 2011).

Research by Komprda et al. (2003), found that the total lipid content in carp was 8.1 g/100 g of fresh tissue, and the total lipid increased linearly and significantly with the increase of live weight. Urbánek et al. (2010), reported that the fat content in the flesh of *cyprinid* ranged from 10 g/kg–100 g/kg. Fat content also affects the quality and texture of the flesh. Carp fed with maize or cereals are found to deposit higher fat in their flesh.

Carp's fatty acid profile

Fatty acids are the leading composer of lipid fraction, a compound that soluble in the organic solvent (Tocher, 2003). Meanwhile, lipids also composed of several fractions, including triacylglycerol, diacylglycerol, monoacylglycerol, phospholipids, steryl-esters, and sterols (Saify et al., 2003). The fatty acid is a non-polar carboxylic acid with long aliphatic chains which may be straight, branched, saturated, or unsaturated (Wang et al., 2017). According to the carbon–carbon bonds, FAs are classified into saturated and unsaturated fatty acids. Later, the unsaturated, which have at least one double bond, are divided into monounsaturated and polyunsaturated fatty acid (Moghadasian & Shahidi, 2016).

Generally, freshwater fish is characterized by a high amount of oleic acid, palmitoleic acid, and arachidonic acid. Fish that live in the cold region maintains a high level of PUFA and monounsaturated fatty acid [MUFA] and low level of saturated fatty acid [SFA]. Meanwhile, fish in the tropical region show a low level of PUFA and a high level of SFA and MUFA. Also, palmitic acid from SFA, oleic acid from MUFA, and EPA and DHA from PUFA are found to be distributed in the high percentage in the fish body (Kaçar, 2019).

Freshwater fish is not only the primary source of protein but also contain nutritionally valuable lipids and fatty acid. The PUFA plays an essential role in the growth, development, and reproduction of all vertebrates. However, vertebrates are not able to synthesis the PUFA, so it must be supplied through diet. In fish, PUFA is dominated by EPA and DHA. (Memon et al., 2011). Most freshwater fish need LA or ALA to synthesize VLCPUFA like AA, EPA, and DHA. The predominance of freshwater fish is its ability to synthesize the VLCPUFA while the seawater fish are unable to do so (Jiao et al., 2020). The natural carp food is rich in n-3 PUFA, so it affects the n-3 content in the flesh. The cereal supplement contained on fish feed has less amount of n-3 PUFA, so it increases the level of lipid and MUFA in the flesh.

A study by (Guler et al., 2008) stated that the type and amount of fatty acid in fish tissue is mainly due to diet and feeding habits. Size, age, reproductive status, and environmental factors such as geographic location and season may also influence the composition. (Özogul et al., 2007) reported that the water temperature could affect the fatty acid content of individual fish on the same species, as the temperature decrease, the unsaturated fatty acid content increase. Also, related to age and sex, younger carp are contained high phospholipid and n-3 but less in MUFA compared to the adult, and the female carp are fattier because of the maturation (Mráz & Pickova, 2011).

Furthermore, another research had compared the four different cross breeds of mirror carp, namely pure line Hungarian, Hungarian and Israeli, hybrid line of two Hungarian carp, and hybrid line of Hungarian and Northern carp. The result showed that the pure line Hungarian carp contained less amount of MUFA and higher PUFA (sum of n-3 and n-6). Correspondingly, there is no correlation between fatty acid composition and the hybrid type. Also the SFA content in all samples showed almost the same amount. Similarly, all samples except the pure line of Hungarian mirror carp were superior with MUFA (Mráz & Pickova, 2009, 2011). The *Figure 1* showed the result of FA from four different cross breed carp.

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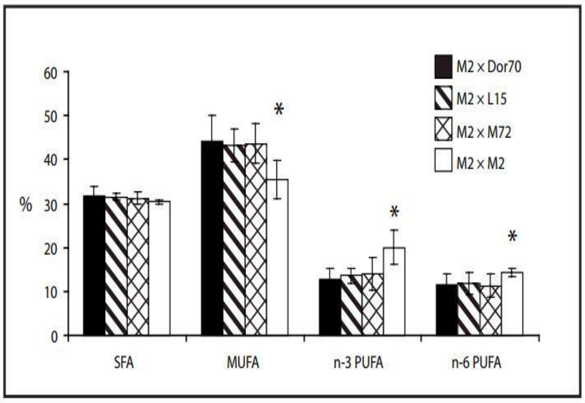
Figure 1. **Amount of FA from Four Different Cross Breed of Mirror Carp**



Note: Hybrid line of Hungarian mirror carp and Israeli mirror carp (M2 x Dor70)
Hybrid line of two Hungarian mirror carp (M2 x L15)
Hybrid line of Hungarian mirror carp and Northern mirror carp (M2 x M72)
Pure line of Hungarian mirror carp (M2 x M2)
Source: (Mráz & Pickova, 2011)

A study by (Balev et al., 2017) observed the flesh quality of scaly and mirror carp from two rearing systems, the conventional as the control and organic system as the experimental. Each rearing system consists of both types of carp. The study found that the type of cultivation plays a significant role in FA composition but showed not significantly different on the amount of each FA from both systems. The table shows that the number of FAs in each sample are nearly in the same amount. However, the highest SFA, MUFA, and PUFA are found in scaly experimental, scaly control, and mirror experimental, respectively. Mirror experimental also exhibit the lowest MUFA among the other samples. The rearing system changes the extent of fatty acid composition, thus increasing the amount of beneficial PUFA and decreasing MUFA. The detailed FAs composition of carp is presented in *Table 1.*

Table 1. **FA Composition of Carp from Different Rearing Media**

Fatty acid (%)	Control system		Experimental system	
	Mirror carp	Scaly carp	Mirror carp	Scaly carp
SFA	30.51	29.49	30.03	**31.48**
MUFA	60.66	**61.63**	57.02	57.26
PUFA	8.83	8.88	**12.95**	11.26

Source: (Balev et al., 2017)

Another study by (Yeganeh et al., 2012) compared each fatty acid profile on wild and farmed common carp in four different seasons. The result of observation on each season showed no significant difference in each type of fatty acid in both carp. Also, it found that palmitic acid and oleic acid are identified as primary SFA and MUFA, respectively, in both carp in all seasons. However, in the case of PUFA, the wild carp is rich in DHA (8.40%), and LA dominates farmed carp. The high amount of LA in farmed carp (15.30%) is a mark that distinct from the wild carp (3.10%). The findings showed that both carp in all seasons contained a higher level of MUFA than those SFA and PUFA. The high level of MUFA was likely due to the feeding habits of the fish. Also, the amount of unsaturated FA has reported increased in the winter season due to temperature variation, food availability, and reproductive status. It indicated the seasonal fluctuation was not significantly affected the FA content in the sample. The result showed in *Table 2.*

Table 2. **FA Composition of Wild and Farmed Carp**

Fatty Acid (%)	Wild carp				Farmed carp			
	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
SFA	22.49	25.33	21.51	24.09	31.72	21.48	20.84	22.64
MUFA	27.15	32.84	30.49	29.72	38.10	43.95	38.19	36.27
PUFA	23.28	16.55	20.73	26.65	19.75	26.31	28.71	31.07

Source: (Yeganeh et al., 2012)

Similar research by (Guler et al., 2008) investigated the fatty acid composition of wild carps in each season. Firstly, the lipid content is found at the lowest level during summer (0.91%) and to be higher in winter (1.73%) as the season, age, and maturity may influence the amount of total lipid. Then, the result showed that palmitic acid and oleic acid are the primary SFA and MUFA, respectively, in carp in all seasons. The carp in all seasons is abundant in PUFA when the highest occurs in summer and the lowest in winter. Feeding habits and diet of fish influence this anomaly. The result showed that the type of fatty acid and its amount might vary depending on the season. However, the statistical analysis result showed no significant difference in the fatty acid profile result of carp in a different season.

Followed by (Jabeen & Chaudhry, 2011), that sampled carp from upstream and downstream river then analyzed its chemical composition. The mean value showed that carp from both sites have palmitic acid as the most abundant SFA and result in the highest proportion of SFA compared to MUFA and PUFA. Moreover, the higher in MUFA and PUFA class is dominated by oleic acid and LA, respectively.

A similar result also reported by (Özogul et al., 2007) that collect and compare several commercially important freshwater fish in Turkey. In common carp, palmitic acid is found in high amounts for SFA while

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in MUFA and PUFA is dominated by oleic acid and DGLA, respectively. However, the highest quantity is dominated by PUFA.

Hong et al. (2014) analyzed the lipid and fatty acid content in three different body parts of various types of wild carp. In common carp, the result showed that the lipid is the highest in the brain (48.69 g/100g), followed by eyes (8.95 g/100g), and muscle (0.64 g/100g). In the muscle, brain, and eyes of common carp, palmitic acid of SFA is the dominant FA, and its content is found the highest in muscle. While oleic acid and LA are dominated the amount of MUFA and PUFA, respectively. The highest amount of oleic acid is found in the eyes, while LA is highest in the brain. In the brain and eyes, MUFA is found in the highest amount. In muscle, the dominant FA is PUFA, as it serves as the primary energy for the muscle to swim and move.

Research by (Rasoarahona et al., 2004) reported the monthly variation of fatty acid and lipid content of common carp from two different locations in Madagascar. The first sample group is pond farmed carp labeled as SIS, and the second sample is wild catch carp labeled as ITA. The monthly variation of fatty acid and lipid content then calculated its mean value and presented in the *Table 3*.

Table 3. **Mean Value of Monthly Variation in FA and Lipid Content from Common Carp**

Loc	FA (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
SIS	n-6	20.44	20.98	–	21.73	21.82	21.56	22.80	23.03	21.40	22.71	21.81	21.34
	n-3	10.49	10.17	–	11.19	11.78	12.81	14.90	15.25	16.75	16.98	13.80	11.32
	lipid	1.05	0.98	–	0.93	1.24	1.38	1.59	1.69	1.73	1.57	1.23	1.13
ITA	n-6	20.38	20.60	20.72	20.60	20.82	22.30	22.82	23.69	23.57	23.39	–	–
	n-3	10.21	11.06	11.08	10.71	11.25	11.44	11.25	14.89	17.67	16.98	–	–
	lipid	0.97	0.95	0.98	0.91	1.19	1.15	1.42	1.56	1.65	1.60	–	–

Source: (Rasoarahona et al., 2004)

According to the table above, the lowest lipid content is from February until April, and it is in correspondence to the spawning period of carp because during this period, dietary and synthesized lipids are mostly used for egg maturation, which needs a considerable amount of FA. The FA composition in this research throughout the year is dominated by oleic acid, palmitic acid, and linoleic acid. It also stated that in major FA, there is no difference appears between both groups indicated by the close amount of FA. The lipid accumulation during the cold season (July–August) followed by the increasing amount of PUFA and decreasing SFA and MUFA during the spawning season. It suggested that during the cold season, carp actively convert dietary LA into n-6 PUFA.

Carp's free fatty acid

Fatty acid in the lipid fraction may present in the form of free fatty acid or as neutral lipids (Saify et al., 2003). The free fatty acid produced from TAG by hydrolytic reactions (Feher, 2017; González et al., 2009). The presence of water combined with enzymatic reactions or heating induced the hydrolysis of ester bonds in lipids, which then could liberate the FFA. During processing or storage, the FFA accumulation influences the shelf-life and quality of the product. It also has an adverse impact on ATPase activity, protein solubility until the quality deterioration, which finally able to decrease consumer acceptance. Its presence can cause textural alteration and unfavorable flavor in foodstuffs (Bernárdez et al., 2005; Kong et al., 2016).

As a result of enzymatic and non-enzymatic lipid hydrolysis, FFA can be used as the lipid quality indicator and does not lead to a nutritional loss (Ehsani & Jasour, 2012). The FFA accumulation leads to the lipid hydrolysis, and the main target of this process is the myofibrillar proteins (Sequeira-Munoz et al., 2006). The loss of extractability of myofibrillar proteins due to FFA formation is faster in lean fish than the higher fat fish; also, it is known that TAG and phospholipid are the substrates for the enzymatic formation of FFA (Sen, 2010).

High metabolic activity of fish related to the higher enzymatic activity. The higher enzymatic activity leads to higher lipolysis post-mortem, which then affects the release of fatty acid from phospholipids. This reaction decreased the total phospholipid and increased FFA. The fatty acid compositions are related to the lipid content. The phospholipid is a component of the cell membrane, which gives a structure of the cell, while TAG plays a role as an energy reserve and stored in adipose tissue (Mráz & Pickova, 2009).

Lipolysis begins with the conversion of TAG into FFA through a complex process involving specific protein and enzymes. The result of lipolysis then used by the body for metabolism activity. FFA formed in the cytoplasm, and its metabolism occurs in the inner mitochondrial matrix by binding the protein, fatty acid, and enzyme systemically to produce energy. Then the produced energy can be utilized and transported to other tissue (Feher, 2017).

TAG is mostly stored either in the liver or skeletal muscle, but the teleost fish like C. carp are known to store TAG in the adipose tissue in the intestine. FFA are transported from the fat to the various utilizing tissue. The highly active fish need higher FFA as the source of energy, so the FFA are transported and directly utilized in the muscle tissue (Larsson & Fänge, 1977). FFA produced by lipolytic activity on all significant lipid class is the main products of lipid

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digestion. The intracellular transport of FFA is facilitated by low molecular weight cytoplasmic protein that bond with LCPUFA, and its rate is related to the amount of nutritional factor, especially the dietary lipid in which its contents can suppress the lipogenesis (Tocher, 2003).

The high level of PUFA characterizes the presence of phospholipid in the muscle. Its proportion is controlled by complex enzymatic systems, such as desaturase and elongates, which responsible for converting LA and ALA to AA, EPA, DPA, and DHA (Abedi & Sahari, 2014). The enzyme which responsible for the TAG hydrolysis called lipoprotein lipase. It also plays a role in lipid metabolism and transport. The hydrolysis produces a non-esterified FA and 2-monoacylglycerol as energy storage for TAG and their use in tissue (Rubio & López, 2016).

Ali et al. (2019) reported that the FFA generated either by phospholipid, neutral lipid (TAG), or both during storage. The enzymatic hydrolysis of esterified lipids can increase the FFA, and it has been used to establish the grade of deterioration. The role and function of FFA are as energy source and energy transport within the body. However, it also can cause oxidative stress in the cell membrane (Binienda et al., 2013). The lipid digestion in fish produces FFA from lipolytic action on all major lipid classes. It occurred in the digestive tract and found high in the intestine. The absorption of the product from lipid digestion in fish are slower compared to mammals due to the lower body temperature (Tocher, 2003).

Balev et al. (2017) conducted a comparative study of two type carp reared in two different systems and found that the rearing system affects the total lipid and free fatty acid of carp. The result showed that the total lipid and free fatty acid content in carp reared in the experimental system are significantly higher than the control system. It indicated that the lipid in the experimental pond was more susceptible to hydrolytic degradation. The results are presented in the *Table 4*.

Another study found that low oxygen supply in tissue may increase FFA and PUFA levels. The low oxygen state in tissue leads the cell damage and energy reduction of protease and lipase. It also stimulates the release of specific hormones that play a role in the mobilization of FFA. White muscle generally contains a low level of FFA while the red muscle store more lipids and has a higher capacity for FA metabolism (Van Den Thillart et al., 2001; Van Raaij et al., 1994).

Table 4. **FFA Composition of Carp from Different Rearing Media**

Indicator	Control system		Experimental system	
	Mirror carp	Scaly carp	Mirror carp	Scaly carp
Total lipid (g/100 g)	5.47	5.82	6.80	6.50
FFA (%)	0.17	0.21	0.32	0.32

Source: (Balev et al., 2017)

Then, during starvation, FFA is released from TAG as a substrate for the β-oxidation in mitochondria. Generally, fish utilize FA selectively to conserve the metabolic process and essential LCPUFA and utilize first the less important FA as the fuel (Zajic et al., 2013). According to (Van Raaij, 1994), the FFA levels depend on the season, temperature, age, and nutritional status. Some fish store their lipid either on the liver or intestine, and the FFA transport via blood would result in a high FFA level in blood. It also reported that FFA in teleost was 5–7 µmol/ml, and the composition of FA is the reflection of the dietary lipids. (Larsson & Fänge, 1977) reported that FFA in carp ranged from 1.1–2.2 µmol/ml. FA primarily ingested from the diet and stored as TAG. However, it cannot be directly absorbed by the intestine and must be broken down into FFA and monoacylglycerol by pancreatic lipase colipase (Stillwell, 2016).

CONCLUSIONS

In general, the fatty acid profile of carp was influenced by external and internal factor. However, the external factor like seasonal variation found that not significantly affect the amount of fatty acid on carp. While, the diet and feeding habits might play a role in the composition and the amount of fatty acid of carp meat.

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