ORIGINAL RESEARCH ARTICLE

Prevalence and Causes of Skeletal Deformities in Cultured Juvenile *Oncorhynchus mykiss*

Prevalencia y causas de deformidades esqueléticas en ejemplares juveniles cultivados de Oncorhynchus mykiss

Prevalência e causas de deformidades esqueléticas em exemplares juvenis cultivados de Oncorhynchus mykiss

Filiz Özcan[1]*

[1]*Dicle University, Veterinary Faculty Fisheries and Fisheries Diseases Department, 21280, Diyarbakır, Türkiye*

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***Corresponding Author:** Dicle University, Veterinary Faculty. Fisheries and Fisheries Diseases Department 21280, Diyarbakır, Türkiye. Email: felizozcan@gmail.com

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Abstract

Background: Skeletal development and the incidence of skeletal deformities in fish are among the most important problems that need to be solved to increase the success of aquaculture. Skeletal deformities reduce the survival, growth, and nutrition of fish. **Objective:** In this study, skeletal deformations were investigated in juvenile *Oncorhynchus mykiss*, the most widely farmed trout in Turkey. **Methods:** Thirty trout farms were visited, and 1200 juvenile individuals were collected and analyzed. In order to determine the skeletal deformations in the collected samples, the observed deformations were divided into groups. The most common pathological findings in individuals were also evaluated. **Results:** As a result of the study, the most common skeletal deformation was compression (C), with a rate of 49.83%. When analyzed according to region, the most deformation occurred in the tail lordosis-kyphosis region, with a rate of 73.17%. On the other hand, when we analyzed the specimens, 61% lordosis was detected. When jawbone deformities, fin deformities, and pterygophore deformities were analyzed, jawbone deformities were found at the highest rate of 12.08 %. The most common pathological finding in the samples was swimming disorder (37.58 %). Another result was the change in total deformation rate depending on different water temperatures in the farms. **Conclusions:** According to the results, the highest deformation rate was found to be 19.58% at 13°. The prevalence of deformities indicates that the environmental conditions in which aquaculture practices are carried out should be regulated as well as the deficiencies in the aquaculture management system.

Keywords: *juvenile fish; Oncorhynchus mykiss; pisciculture; skeletal deformities.*

Resumen

Antecedentes: El desarrollo esquelético y la incidencia de deformidades esqueléticas en los peces se encuentran entre los problemas más importantes que deben resolverse para aumentar el éxito de la acuicultura. Las deformidades esqueléticas reducen la supervivencia, el crecimiento y la nutrición de los peces. **Objetivo:** En este estudio, se investigaron las deformaciones esqueléticas en juveniles de *Oncorhynchus mykiss*, la trucha más cultivada en Turquía. **Métodos:** Se visitaron treinta granjas de truchas y se recolectaron y analizaron 1200 individuos juveniles. Para determinar las deformaciones esqueléticas en las muestras recolectadas, las deformaciones observadas se dividieron en grupos. También se evaluaron los hallazgos patológicos más comunes en los individuos. **Resultados:** Como resultado del estudio, la deformación esquelética más común fue la compresión (C) con una tasa del 49.83%. Cuando se analizó según las regiones, la mayor deformación se produjo en la región de lordosis-cifosis de la cola con una tasa del 73.17%. Por otro lado, al analizar los especímenes se detectó un 61% de lordosis. Al analizar las deformidades de los huesos maxilares, de las aletas y de los pterigóforos, las deformidades de los huesos maxilares se encontraron con la tasa más alta con un 12.08%. El hallazgo patológico más común en las muestras fue el trastorno de la natación (37.58%). Otro resultado fue el cambio en la tasa total de deformación en función de las diferentes temperaturas del agua en las granjas. **Conclusiones:** De acuerdo a los resultados, la tasa más alta de deformación se encontró con un 19.58% a 13°.La prevalencia de deformidades indica que se deben regular las condiciones ambientales en las que se realizan las prácticas acuícolas, así como las deficiencias en el sistema de gestión acuícola.

Palabras clave: *deformidades esqueléticas; juvenil; piscicultura; Oncorhynchus mykiss.*

Resumo

Antecedentes: O desenvolvimento esquelético e a incidência de deformidades esqueléticas nos peixes estão entre os problemas mais importantes que devem ser resolvidos para aumentar o sucesso da aquacultura. As deformidades esqueléticas reduzem a sobrevivência, o crescimento e a nutrição dos peixes. **Objetivo:** Neste estudo foram investigadas deformações esqueléticas em juvenis de *Oncorhynchus mykiss*, a truta mais cultivada em Türkiye. **Métodos:** Foram visitadas 30 explorações de truticultura e recolhidos e analisados 1.200 indivíduos juvenis. Para determinar as deformações esqueléticas nas amostras recolhidas, as deformações observadas foram divididas em grupos. Os achados patológicos mais comuns nos indivíduos também foram avaliados. **Resultados:** Como resultado do estudo, a deformação esquelética mais comum foi a compressão (C) com uma taxa de 49.83%. Quando analisado por região, a maior deformação ocorreu na região lordose-cifose da cauda com um índice de 73.17%. Por outro lado, ao analisar os espécimes, detetou-se 61% de lordose. Ao analisar as deformidades dos ossos maxilares, barbatanas e pterigóforos, foram encontradas deformidades dos ossos maxilares com uma taxa mais elevada de 12.08%. O achado patológico mais comum nas amostras foi o distúrbio da natação (37.58%). Outro resultado foi a alteração da taxa de deformação total em função das diferentes temperaturas da água nas explorações. **Conclusões:** De acordo com os resultados, a maior taxa de deformação foi encontrada com 19.58% no 13°. da aquicultura.

Palavras-chave: *deformidades esqueléticas; juvenil; Oncorhynchus mykiss; piscicultura.*

Introduction

The aquaculture sector is experiencing rapid growth on a global scale with a significant impact on food security (Kebede and Habtamu 2016). Aquaculture production demonstrated a 6.2% increase in 2022 compared to the previous year, reaching 849,808 tons. Of the total production, 30% was constituted by marine fish obtained through hunting, 5.6% by other marine products obtained through hunting, 3.9% by inland aquatic products obtained through hunting, and 60.6% by aquaculture products (Tuik, 2023). Deformities in fish are a common and serious problem in aquaculture and pose an economic challenge (Noble *et al.,* 2012). The study of these abnormalities and deformations has a long history, dating back to the sixteenth century. Since that time, a large number of studies have been conducted, reporting a variety of deformities observed in fish (Jawad *et al.,* 2016). Deformities have a significant impact not only on aquaculture operations but also on the global conservation and survival of endangered fish species (Chandra *et al.,* 2021). The most important deformities are the spinal deformities, which are vital structural components that affect swimming. Indeed, spinal deformities have the potential to highly affect swimming performance (Powell *et al.,* 2009). Spinal deformities can occur with different types of vertebral body deformities and different types of curvatures that occur together or separately (Witten *et al.,* 2009). It has been determined that skeletal malformations affecting the head, spine, and appendicular skeleton are related to the rearing style and conditions. As a result, the economic importance of such deformities is clear. However, jaw abnormalities such as upper or lower jaw torsion and upper or lower jaw extension impair the feeding ability of the fish. This can eventually lead to starvation and fish death (Boglione *et al.,* 2013). Various factors, such as physico-chemical properties of the water (temperature, pH, salinity, water flow rate), pollution, nutrition, genetic factors, and aquaculture infrastructure, cause deformities (Fopp *et al.,* 2022). Identification of deformities can provide fish farms with a tool to predict abnormalities in adult stages or allow modification of abiotic or biotic factors to improve sample quality during growth (Yıldırım *et al.,* 2014). In this study, deformities occurring at the juvenile stage in rainbow trout farms were analyzed, and this study aims to identify their causes.

Materials and methods

Ethical statement

The authors declare that all ethical rules were followed throughout the research. The study does not have any requirement for ethical approval.

Fish Sampling

Thirty trout farms were visited during the study. Deformed individuals with an average live weight of 5-15 g were sampled. A total of 1200 samples were analyzed. Water temperatures in the farms varied between 9 C°-13 C°. The oxygen concentration of the water samples was found to be in the range of 8.9 to 8.5 mg/L (Table 1).

Table 1. The number of farms included in the study, the parameters used to assess water quality, and the number of samples collected from each farm are presented in the table.

	Temperature of the aquaculture water	Level of oxygen in the water	Number of farms sampled	Number of fish collected from farms	Total number of samples	Average live weight of fish
A Farms	9°	8.9 mg/L	8	40 fish	320 fish	5-15 gr
B Farms	10°	8.9 mg/L	8	40 fish	320 fish	5-15 gr
C Farms	11°	8.7 mg/L	4	40 fish	160 fish	5-15 gr
D Farms	12°	8.7 mg/L	5	40 fish	200 fish	5-15 gr
E Farms	13°	8.5 mg/L	5	40 fish	200 fish	5-15 gr

The table below presents the feeds and nutritional contents used in fish farming. The feeds utilized in fish farming operations are sourced from a range of commercial entities, and their nutritional profiles exhibit considerable variation (Table 2).

Table 2. The feeds and nutritional contents utilized in fish farming operations.

	Feed 1 (A farms)	Feed 2 (B Farms)	Feed 3 (C farms)	Feed 4 (D and E farms)
Protein Content	57.3 %	55.4 %	55.4 %	55.4 %
Crude fat	12.5 %	14.89 %	12.5 %	11.5 %
Cellulose	0.5 %	1.59 %	1.2 %	0.6 %
Crude Ash	13 %	12.19 %	12 %	11 %
Phosphorus	1.99 %	1.80 %	1.60%	1.5 %

Calcium	3.20	3.21%	3.20%	3.00 %
Lysin	3.30 %	3.25 %	3.30 %	3.75 %
Metionin	1.80 %	1.55 %	1.80 %	2 %
Vitamine A	4500 ui/kg	5200 ui/kg	5250 ui/kg	5250 ui/kg
Vitamine D3	1125 ui/kg	1215 ui/kg	1230 ui/kg	1235 ui/kg
Vitamin E	225 mg/kg	215 mg/kg	220 mg/kg	225 mg/kg
Vitamin C	165 mg/kg	155 mg/kg	165 mg/kg	165 mg/kg

Clinical examination

The most notable pathological findings observed during the sampling process at fish farms were swimming disorders, general weakness, and exophthalmus. A clinical examination was conducted on the samples, and the results were recorded. In order to determine the skeletal deformations in the samples collected, the deformations observed were divided into groups. The first group; Compression (C), Fusion (F), Compression and Fusion (C&F), Fusion center (FC), dorsally wedged vertebrae (W), compressed and dorsally wedged vertebrae (C&W) Reduced intervertebral space (R) (Mariasingarayan *et al.* 2024). The second group is defined as jaw bone malformation (JBM), fins (F), pterygophore malformation, epural malformation, and hypural malformation. X-rayed with an EcoRay Toshiba®apparatus. The presence of skeletal deformations was established through a detailed examination of the samples.

Results

1200 samples collected from farms were analyzed. As a result of the examination, Compression (C) was found to be the most common skeletal deformation, with a rate of 49.83%. This was followed by fusion center (48.33%; FC), compression and fusion (30.83%; C&F), fusion (29.75%; F), compressed and dorsally wedged vertebrae (22.75%; C&W), reduced intervertebral space (16.58%; R), dorsally wedged vertebrae (5.75%; W). When analyzed by region, the highest deformation occurred in the lordosis-kyphosis region of the tail, with a rate of 73.17%. The deformation rates in the whole-body kypho-lordo-kyphosis and tail region kypho-lordosis regions were 66.67% and 64%, respectively (Figure1, Table 3).

Table 3. Vertebral (V) deformity classification of *Oncorhynchus mykiss* species collected from farms.

	Vertebral column category	Compression (C)	Fusion (F)	Compression and Fusion (C&F)	Fusion center (FC)	Dorsally wedged vertebrae (W)	Compressed and dorsally wedged vertebrae (C&W)	Reduced intervertebral space (R)
Tail region lordo-kyphosis	Platyspondyly	112	55	33	4	7	51	26
	Normal	58	32	21	19	3	23	12
(Total :73.17%)	Lordosis	79	21	17	44	5	33	15
	Kyphosis	43	35	45	65	1	12	7
	Total	329	162	143	164	25	138	79
	%	24.33	11.92	9.67	11.00	1.33	9.92	5.00
Tail region kypho-lordosis	Platyspondyly	52	44	22	22	2	27	11
	Normal	23	27	54	67	12	16	9
(Total :64%)	Lordosis	66	34	51	21	7	25	21
	Kyphosis	31	19	47	11	7	17	23
	Total	213	137	213	148	40	106	95
	%	14.33	10.33	14.5	10.08	2.33	7.08	5.33
Whole body kypho-lordo-kyphosis	Platyspondyly	51	24	38	76	6	21	15
	Normal	38	11	9	32	5	19	32
(Total :66.67%)	Lordosis	27	32	13	178	11	21	11
	Kyphosis	18	23	20	41	3	8	17
	Total	149	107	97	386	43	86	86
	%	11.17	7.50	6.667	27.25	2.08	5.75	6.25
Total	**%**	49.83	29.75	30.83	48.33	5.75	22.75	16.58

Figure 1. Lordosis, kyphosis, and scoliosis (a, b, c), deformation of the upper jaw (d), deformation of the lower jaw (e and f), and spinal curvatures (g, h) are observed.

On the other hand, when we examined the specimens, lordosis was found in 61%. This was followed by scoliosis (41.67%) and kyphosis (41.08%) (Figure 1, 2). In jaw bone deformities, fin deformities, and pterygophore deformities, jawbone deformities were found in 12.08%. This was followed by Fins deformities with 8.25% and Malformed pterygophore with 4.42%. In epural and hypural deformities, epural deformities were noted in 44.33% (Figure1, 2).

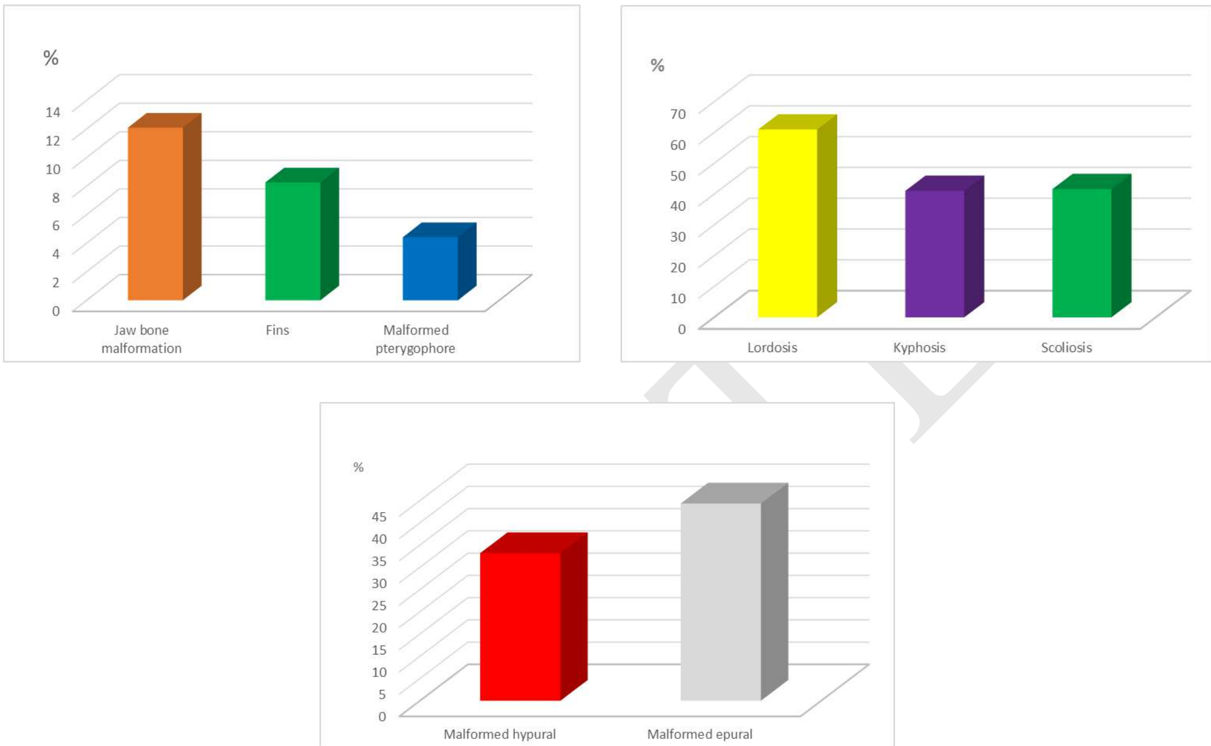


Figure 2. Rates of other malformations detected.

The most common pathological finding in the samples collected was impaired swimming (37.58%). This was followed by weakness (26%), food insensitivity (23.27%), rapid opening and closing of gills (22.83%), unresponsiveness (19.58%), color change (9.42%), and exophthalmos (7.25%) (Figure 3). A further outcome of note is the alteration in the overall deformation rate in response to disparate water temperatures within the farms environment. Pursuant to the findings, it was determined that the maximum deformation registered at 19.58% at an angle of 13C°. This was followed by 12C° (10.75%), 11C° (7.75%), 10C° (5.67%) and 9C° (4.75%) (Figure 3).

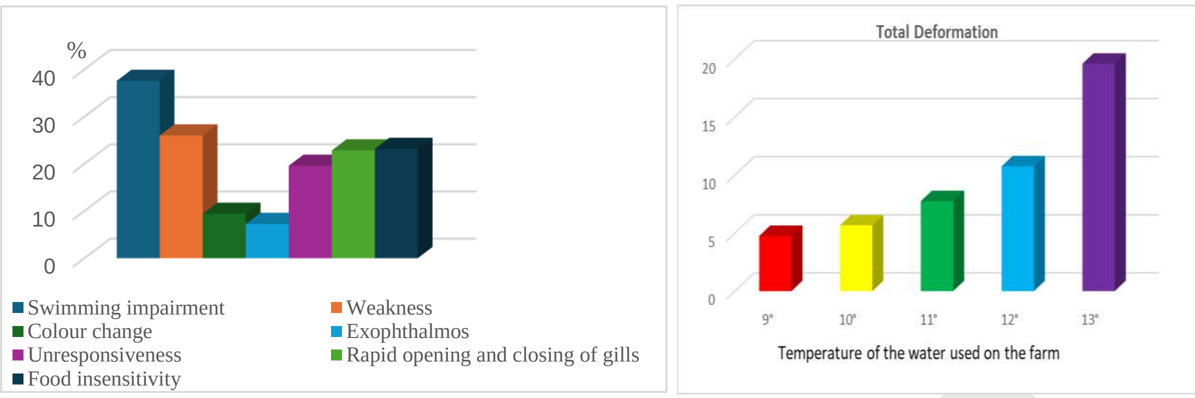
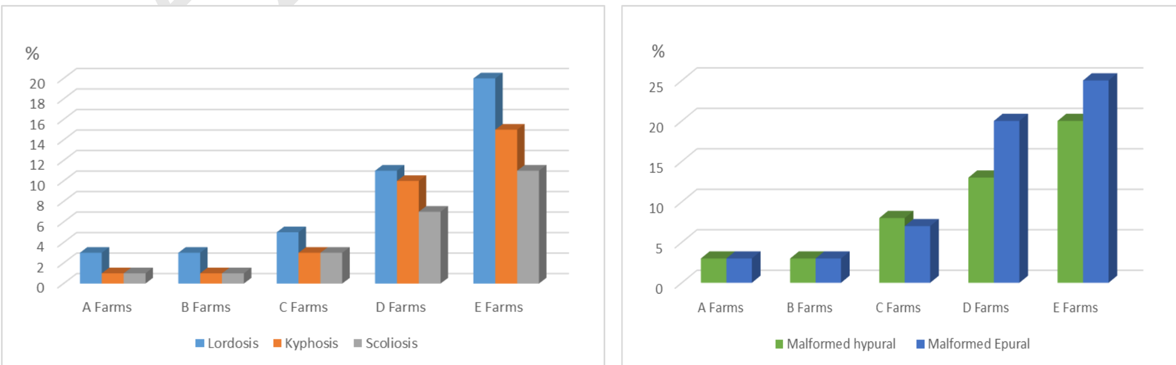


Figure 3. The most common findings in the samples and Total deformation by water temperature in farms

As indicated in the table presented in Material Method, the farms were classified into five distinct groups. The data in this table demonstrate that the water temperatures, oxygen levels, and commercial feeds utilized by the farms exhibit notable variation. Consequently, the farms were evaluated as individual units within their respective groups, and the observed skeletal deformations are presented in this section. The highest rates of lordosis, kyphosis, and scoliosis were observed among fish farm groups, with 20%, 15%, and 11% of farms in group E exhibiting these deformations, respectively. In comparison, the lowest percentages of these deformations were observed in farms in group A. (Figure 4) The most significant deformations, characterized by jawbone malformation and fins, as well as malformed pterygophore, were identified with the highest incidence and at the same rate in fish farms within groups D and E. Conversely, the lowest prevalence of these deformations was observed in fish farms within group A (Figure 4) The prevalence of other noteworthy deformities, namely malformed hypural and epural, was found to be the lowest in fish farms belonging to groups A and B, while the highest rates were observed in those falling under groups D and E (Figure 4.)



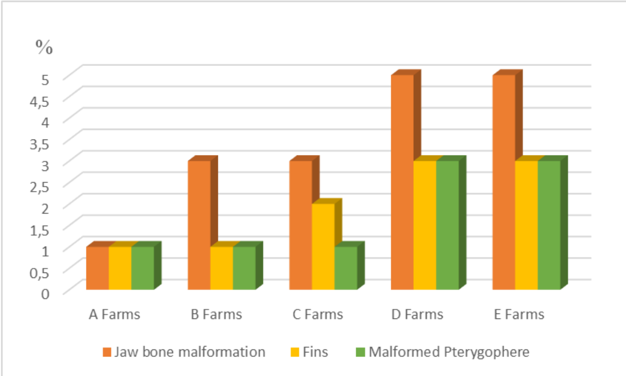


Figure 4. Fish farm deformation rates

Discussion

The occurrence of skeletal deformities during fish growth and development does not only affect the external morphology. However, impaired mobility can result in growth retardation, malnutrition, and ultimately death. Fish with deformed morphology are often discarded during harvest because they are not desirable for consumers. Such events lead to significant economic losses in farms. These losses have been documented by Berillis *et al.* (2015) and Fragkoulis *et al.* (2019). Many types of deformations are observed in fish.The most common deformations are kyphosis, scoliosis, lordosis, mandibular deformities, and vertebral fusion (Eissa *et al.,* 2009). A plethora of factors have been posited as potential etiological agents for these malformations, including, but not limited to, nutritional deficiency, environmental conditions, the presence of toxic substances, physical restraint, agricultural practices, disease, and genetic factors (Ashaf *et al.,* 2021). The investigation revealed that Compression (C) was the most prevalent skeletal deformity, with a prevalence rate of 49.83%. Subsequently, the most prevalent deformities were fusion center (48.33%; FC), compression and fusion (30.83%; C&F), fusion (29.75%; F), compressed and dorsally wedged vertebrae (22.75%; C&W), and reduced intervertebral space (16.58%; R). The least common deformities were dorsally wedged vertebrae (5.75%; W). Upon analysis by region, the highest deformation was observed in the lordosis-kyphosis region of the tail, with a rate of 73.17%. The deformation rates in the kypho-lordo-kyphosis regions of the whole body and the kypho-lordosis region of the tail were 66.67% and 64%, respectively (Table 1). Many studies have reported the occurrence of skeletal deformities in fish species (Lv *et al.,* 2019). One of the most important challenges in intensive aquaculture is the abundance and prevalence of skeletal malformations, especially lordosis, kyphosis, scoliosis, and vertebral fusion. The aetiology of these deformities is multifactorial. The most important of these factors are nutrition, environmental conditions, farming practices, and genetic factors (Georgakopoulou *et al.,* 2010). The most common and most common external deformities in fish are kyphosis, scoliosis and lordosis, which can be seen in the abdominal region of the vertebral column. These deformities can be detected at an early stage. As a result, these deformities can be evaluated externally during rearing, and if necessary, fish showing such deformities can be removed from the population before they reach marketable size. Other malformations may be observed, including deformities of the pterygiophores of the dorsal and anal fins, vertebral fusion, and deformities of the caudal complex. These malformations do not affect the external shape of the fish but can be observed during rearing (Boglione *et al.,* 2013). Indeed, the study revealed that lordosis was present in 61% of the subjects. This was followed by scoliosis (41.67%) and kyphosis (41.08%) (Figure 2). In the case of jawbone deformities, fin deformities, and pterygophore deformities, it was found that 12.08% of the subjects exhibited jawbone deformities. The next most prevalent deformities were fins, with an incidence of 8.25%, and malformed pterygophores, with an incidence of 4.42%. The development of the head and jaw is a complex and difficult process that involves the coordinated operation of multiple genes (Delaurier *et al.,* 2019). A study conducted by Babaheydari et al. (2016) analyzed hatched rainbow trout (*Oncorhynchus mykiss*) larvae to determine differences in protein expression between normal and deformed fish. This study provided preliminary information on the molecular mechanisms underlying skeletal malformations in fish by identifying nine protein regions that were altered in deformed fish. However, the authors also emphasized that further validation studies using mRNA expression techniques or antibody-based analyses are needed to use these proteins as indicators of skeletal deformity. Such studies are of great importance in understanding the relationship between skeletal deformity and genetic factors. A review of the available evidence revealed that epural and hypural deformities were present in 44.33% (Figure 2) of the specimens examined. The structural integrity and durability of the mineral content play an important role in the protection of fish spines (Fjelldal *et al.,* 2018). As a result, vertebrae with low mineral content are hard and weak, which may lead to the development of a compressed formation. Furthermore, despite the fact that all vertebrae along the vertebral column exhibit low mineral content, the development of mineralization-related deformities is, as a general rule, regional. This phenomenon may be indicative of the location where the load exerted by the lateral muscles is greatest, and the ontological situation in which the deformity occurs. (Fjelldal *et al.,* 2021). As previously indicated, specific deformities have been identified in cultured fish species, which have the potential to impact various biological processes, including growth, swimming, feeding, resistance, speed, and survival (Berillis 2017). It can be reasonably inferred that the pathological findings observed in the fish in this study provide support for this hypothesis. The most frequently observed pathological condition in the sampled fish was impaired swimming, which occurred in 37.58% of cases. The most prevalent pathological manifestations were observed to be weakness (26%), food insensitivity (23.27%), the rapid opening and closing of gills (22.83%), unresponsiveness (19.58%), color change (9.42%), and exophthalmos (7.25%) (Figure 3). Severe skeletal deformities mean the selective removal of individuals with significant deformities from the population. Such practices cause significant economic losses for the stabilization and preservation of stock quality (Rutkayov *et al.,* 2016). Studies have determined the existence of biotic and abiotic factors underlying skeletal deformities in fish (Park *et al.,* 2016). Changes in water temperature can affect skeletal formation and lead to morphological malformations (Fraser *et al.,* 2015). Another important area of interest in biological research is the effect of environmental factors on the developmental processes of fish. Temperature is the most important factor affecting fish development, including survival, nutrition, and possible deformities (Fraser *et al.*, 2015). Accordingly, temperature has been determined as the "main abiotic factor" for the development of fish (Güralp *et al.,* 2017). In addition, temperature level has an important effect on body deformities, nutrition, ontogenetic development, and growth and survival of fish (Kim *et al.,* 2018). An increase in water temperature has been reported to be an effective method to increase growth rate and production in cold water aquaculture. However, this method has also shown that high temperatures are a factor contributing to the increased frequency of skeletal deformities (Ytteborg *et al.,* 2010). A review of the scientific literature reveals that the optimal water temperature for *O. mykiss*, a type of rainbow trout, is 10°C. Temperatures above 14 °C are detrimental, and below 6 °C are suboptimal. The most common skeletal malformations observed in rainbow trout (*Oncorhynchus mykiss*) are compression or fusion vertebrae (Lein *et al.,* 2009). *Pagellus erythrinus* displays a 75% prevalence of deformities in unfavorable temperature conditions due to its developmental plasticity (Sfakianakis *et al.,* 2004). The present study revealed that an elevated rate of deformity was observed in organisms as the cultivation temperatures increased. The change in total deformation rate due to different water temperatures in the farms was found to be 19.58% at 13°, followed by 12° (10.75%), 11° (7.75%), 10° (5.67%) and 9° (4.75%) (Figure 3). This result is corroborated by the findings of Han et al. (2020), which revealed a greater prevalence of deformities in *T. ovatus* at 32°C. Among the observed deformities, the most prevalent was lordosis of the vertebral column in the caudal region of the organisms, occurring in 61% of cases. This is in accordance with the findings of Andrades et al. (1996), who identified lordosis as the most prevalent type of deformity among fish. A balanced diet, including an appropriate quantity and proportion of nutrients, such as protein, carbohydrates, lipids, vitamins (A, D, E, K, and C), and minerals (phosphorus, calcium, and trace elements), is essential for the optimal growth and development of fish. Any deviation from the optimal level, excess or deficiency of nutrients, can impair growth and development and lead to deformities in fish. Malnutrition has been identified as a significant contributing factor to deformities in fish. It has been demonstrated that inadequate nutrition can result in malformations, particularly at an early developmental stage (Liang *et al.,* 2017). A deficiency of vitamins C and E, for instance, can lead to bone and muscle disorders in fish, a phenomenon that has been demonstrated by Näslund et al. (2016) and other research studies. Deficiencies in vitamins C and K have similarly been associated with skeletal deformities in fish, with evidence suggesting that they affect bone mineralization in several species (Darias *et al.,* 2011). Deficiencies in vitamin C in diets have been linked with the occurrence of spinal deformities, including lordosis, in a range of species, including rainbow trout (*Oncorhynchus mykiss*), Japanese halibut (*Paralichthys olivaceus*) and cichlids (Berillis *et al.,* 2015). Furthermore, deficiencies in vitamin C have been associated with the development of scoliosis and lordosis in channel catfish (*Ictalurus punctatus*). Conversely, a variety of biotic factors, encompassing pathogenic infections, genetic predisposition, and the circumstances under which fish are bred or reared in captivity, can give rise to deformities in fish. It has been demonstrated that some factors result in the formation of malformations in both adult fish and their offspring, while others have been found to only affect the latter. Disease outbreaks and infections have been observed to cause a range of malformations in fish, including kyphosis, cranial cavitation, and spinal and skeletal anomalies. (Chandra *et al.,* 2024)

Deformations of various types are commonly observed in fish specimens. Among the most frequently occurring deformations are kyphosis, scoliosis, lordosis, mandibular deformities, and vertebral fusion (Eissa *et al.,* 2009). The etiology of these malformations has been associated with a multitude of potential causes, including nutrient deficiency, environmental conditions, toxic substances, physical restraint, farming practices, disease, and genetic factors (Ashaf *et al.,* 2021). A plethora of studies have demonstrated a correlation between fish deformities and the presence of heavy metals. Such deformities have been shown to have a profoundly deleterious effect on fish populations, impacting their survival, growth rate, welfare, and external morphology. Fish deformities, particularly those affecting the skeletal system, are of particular concern as they can hinder an organism's capacity to interact effectively with its environment (Demir *et al.,* 2024).

Indeed, the study revealed notable discrepancies in the prevalence of severe skeletal deformations across different fish farms. A review of the results indicates that the observed differences may be attributed to the aforementioned factors. A comparative analysis of aquaculture farms indicates that the most significant variations are observed in the composition of their feed and the temperature regimes under which the fish are cultivated. The study revealed that skeletal deformations were the least prevalent on farms where the water temperature was maintained at 9°C. In 2009, Lein provided support for our study by stating that 10°C was the optimal temperature for rainbow trout, 14°C was too high, and that fused or compressed vertebrae were the most common skeletal malformations observed in farms conducted at high temperatures. The findings of this study indicate that an increase in water temperature is associated with a rise in the prevalence of skeletal deformities. The water temperature exerts a considerable impact on the incidence of jaw deformities in the golden pompano (*Trachinotus ovatus*). The prevalence of these deformities is observed to be at its peak at a temperature of 33°C and at its lowest point at 26°C, indicating a clear correlation between jaw deformity and high water temperature (Lein, 2009). The highest incidence of jaw malformation was observed in Group E farms with the highest water temperature, while the lowest incidence was observed in Group A farms with a water temperature of 9°C. A further significant factor to be considered in the study is the diverse range of feeds provided to the fish. The nutritional composition of each feed differs. It is essential to provide fish with an appropriate quantity and ratio of different nutrients, including protein, carbohydrates, lipids, vitamins (A, D, E, and C), and minerals (phosphorus, calcium, and trace elements), to ensure normal growth and development (Cahu *et. al.,* 2003) Any deviation from the optimal level, whether excess or deficiency of nutrients, may impair growth and development, and induce deformities in fish. Malnutrition represents a significant contributing factor to the development of deformities in fish. Insufficient nutrition, particularly during the early stages of development, has been identified as a key factor in the emergence of malformations (Liang *et al.,* 2017). A deficiency of essential nutrients, such as vitamins C and E, can lead to bone and muscle disorders in fish (Näslund *et al.,* 2016). A deficiency in vitamin C has been observed to result in the development of lordosis in several species of fish, including rainbow trout (*Oncorhynchus mykiss*), Japanese flounder

(*Paralichthys olivaceus*) and cichlids (Darias *et. al.,* 2011). Vitamin A deficiency increased the incidence of mouth deformities in the Japanese flounder, P. olivaceus. Hernandez And Hardy (2020) discovered that elevated levels of vitamin A in dietary regimens may disrupt the typical coordination between bone development and bone matrix formation, leading to the emergence of skeletal deformities. Vitamin A has a beneficial effect on the maturation of chondrocytes and the activity of osteoclasts. It also has an enhancing impact on vertebral column development and a suppressive effect on bone matrix formation, which can result in vertebral and jaw deformities. The primary components of bones are inorganic salts, calcium, and phosphorus. Deficiency of phosphorus results in a range of deformities, including growth retardation, skeletal deformities, soft bones and a curved spine in Atlantic salmon (*Salmo salar*), cephalic anomalies of the frontal bones in mirror carp, and twisted neural and haemal spines in Atlantic halibut and juveniles of haddock. The study revealed notable differences in the levels of various vitamins, including Vitamin A, Vitamin D3, Vitamin E, and Vitamin C, in the commercial feeds provided to the fish farm groups. The highest rates of skeletal deformation are observed in the D and E fish farm groups, which were fed the greatest quantity of vitamin A in the commercial feed. The elevated water temperature in these farms, along with the findings of Hernandez and Hardy (2020), which indicated that elevated vitamin A levels in dietary regimes can disrupt the typical coordination between bone development and bone matrix formation, thereby accelerating skeletal deformities, are both confirmed. Conversely, an examination of the phosphorus and calcium rates in the feeds reveals that these are low in the same groups. A deficiency of phosphorus can result in growth retardation, skeletal deformities, soft bones, and a curved spine in Atlantic salmon (*Salmo salar*) (Silverstone, 2002). The combination of a low level of these components, a high water temperature, and a high value of vitamin A may have contributed to the increased prevalence of skeletal deformities observed in fish fed with these feeds. It can be reasonably deduced that the aforementioned factors may have contributed to the prevalence of deformities observed in the fish farms in question. The impact of fatty acids, particularly DHA, on developmental processes in mammals and amphibians is becoming increasingly clear. Dietary fat exerts a profound influence on gene expression, leading to alterations in metabolic processes, growth patterns, and cell differentiation. Fatty acids, and particularly highly unsaturated fatty acids, act on the genome through specific nuclear receptors such as Peroxisome Proliferator Activated Receptors (PPARs). This receptor binds to DNA as a heterodimer with the retinoid X receptor (RXR), which regulates genes involved in skeletal development during ontogeny. It may therefore be hypothesized that highly unsaturated fatty acids affect skeletal formation during development in this way (Cahu *et. al.,* 2003). Upon examination of the feed groups in light of the aforementioned information, it becomes evident that the lowest crude fat content is observed in the feeds provided to fish in groups D and E. Consequently, it can be postulated that deformation may have been a prevalent phenomenon in fish fed with this particular feed.

Conclusion

The study revealed a correlation between elevated water temperatures and increased skeletal deformation. The lowest levels of deformation were observed in fish farms with a water temperature of 9°C in group A. The deformation observed was found to be affected by both water temperature and the nutrient content of commercial feeds. Further studies are required to investigate the levels of vitamin A and vitamin D3 present in commercial feeds. It can be posited that an excess of Vitamin A is a contributing factor to skeletal deformation in the presence of elevated water temperatures. It is also important to consider the levels of phosphorus and calcium, which have been linked to deformations. The necessity for the rapid development of cost-effective, farmer-friendly, and robust methodologies for the early detection of deformities in fish and the determination of their causative factors cannot be overstated. The prevalence of deformities indicates the presence of shortcomings in the system of aquaculture management, as well as the environmental conditions under which aquaculture practices are conducted.

Declarations

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The authors declare that they have not received financial resources for the conduct of this research.

Data availability

All data generated or analyzed during this study are included in this article.

Conflict of Interest

The author declares that there is no conflict of interest related to this work.

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