Temperature sensitivity of skeletal development in *Oreochromis niloticus* (Teleostei: Cichlidae)

Mazaher ZAMANI-FARADONBE, Yazdan KEIVANY*

Department of Natural Resources (Fisheries Division), Isfahan University of Technology, Isfahan 84156-83111, Iran.

*Email: keivany@cc.iut.ac.ir*

Abstract: The development of cartilaginous and osteological structures of the dorsal, anal and caudal fins, and axial skeleton in Nile tilapia (*Oreochromis niloticus*) was studied under three temperature treatments (22, 28 and 34ºC). Fish samples were collected periodically during the developmental stage from hatching up to 39 days post hatching. Bone and cartilage development were evaluated. The results showed that the pattern and sequence of development and appearance of these elements in the three treatments are similar, and the difference is in timing of appearance and ossification of skeletal elements. Samples from 34ºC started and ended bone formation earlier, but these process in 22ºC treatment was very late. The temperature on the onset and end of chondrogenesis and ossification had a profound effect; these effects on 22ºC treatment were severe than other treatments. The sequences of the chondrogenesis and ossification process was well conserved at all temperature treatments.

Keywords: Development; Skeleton, Bone, Cartilage, Ontogeny.


Introduction

Water temperature is a critical factor during early developmental stages of fishes affecting their phenotype by modifications of the relative timing of different organs development (Rana 1990; Thépot & Jerry 2015), morphometric and meristic counts (Murray & Beacham 1988; McCormick & Molony 1995; Campinho et al. 2004; Eagderi et al. 2015, 2017), swimming performance (Sfakianakis et al. 2011), yolk absorption (Klimogianni et al. 2004; Lahnsteiner et al. 2012; Barón-Aguilar et al. 2013), muscle ontogeny (Johnston et al. 2009), skeletal development and deformities (Povlov & Moksness 1997; Campinho et al. 2004; Sfakianakis et al. 2006; Georgakopoulou et al. 2010) and sex determination (Abucay et al. 1999; Pavlidis et al. 2000; Blázquez et al. 2009). The magnitude and direction of the temperature effects depend on factors such as species and its developmental stage, and different phases of the fish's life presenting different temperature requirements and resistance (Herzig & Winkler 1986).

It is important to understand the development of cartilage and bone elements in fish from both aspects of fisheries and aquaculture (Farhang & Eagderi 2019). From the aquaculture aspect, understanding the developmental biology of cultured fish is a prerequisite and important for early detection and prevention of skeletal deformities under culture conditions, as many skeletal deformities are created in the early stages of life (Koumoundouros et al. 2000). Some studies have provided morphological development in *Nimbochromis venustus* (Saemi-Komsari et al. 2019) and *Pterophyllum Scalare* (Eagderi et al. 2017), skeletal development and bone deformities in various species of tilapias such as *Hemichromis bimaculatus* (Huysseune 1990; Huysseune & Sire 1992), *Astatotilapia burtoni* (Huysseune 1990), *Oreochromis mossambicus* (Campinho et al. 2004) and Nile tilapia (*O. niloticus*)...
In the present study, we investigated the influences of different temperature treatments on skeletal ontogenesis of Nile tilapia.

Materials and Methods

Adults of *O. niloticus* were maintained in 300 liter freshwater tanks at 28°C under a natural photoperiod (June-October) fed commercial pellets (Kimiagaran-e Taghziyeh, Iran). In each tank, three males and three females were introduced and every 22 days, the dominant female spawn. Spawning and fertilization were carried out in less than 15 minutes as following: the released batch of eggs by dominant female was fertilized by the dominant male and immediately scooped into the mouth of the female. For next steps, the fertilized eggs were collected from the mouth of females, and transferred to vertical incubators with water temperature of 28°C. Then, immediately hatched larval were divided into three 65L aquaria with 22, 28 and 34°C, respectively. Temperature treatments include two threshold tolerable temperatures (22 and 34°C) with optimum temperature of 28°C as control (Bardach et al. 1972). Three different groups of eggs were used as replicates of the experiment. After yolk-sac absorption, commercial food was used to fed free-swimming larvae.

The larvae of the three treatments were reared from hatching upto 39 days post hatching by feeding in the morning. They were anesthetized using the standard anesthetic solution (MS222) and then preserved in 4% buffered formalin after 40 DPH. Samples (10 specimens for each treatment) were collected on 1, 2, 3, 4, 5, 7, 9, 11, 14, 17, 20, 23, 27, 31, 35 and 39 DPH (Table 1).

For osteological examinations, the specimens of 1-40 DPH were cleared and stained with alizarin red S and alcian blue according to Darias et al. (2010). Then, the specimens were studied using a stereomicroscope (hp, smp-120), and skeletal elements were dissected and scanned by a scanner equipped with a glycerol bath (HP Scanjet G4050). The skeletal elements were draw using CorelDrawX7 software. Nomenclature and abbreviations of skeletal elements fallowed Campinho et al. (2004) and Mair (1992).

Results

Dorsal fin development (Figs. 1-3):

Day 0-1 (hatching): No dorsal fin skeletal structures were visible.

Day 2: In specimens of 34°C treatment, the pterygiophore cartilaginous elements (distal and

### Table 1. Total length (TL: Mean±SD)—age distribution of *Oreochromis niloticus* larvae used in the study.

<table>
<thead>
<tr>
<th>Age (dph)</th>
<th>22°C</th>
<th>28°C</th>
<th>34°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.83±0.53</td>
<td>5.69±0.26</td>
<td>5.79±0.42</td>
</tr>
<tr>
<td>2</td>
<td>5.33±0.19</td>
<td>5.89±0.15</td>
<td>7.39±0.43</td>
</tr>
<tr>
<td>3</td>
<td>5.62±0.46</td>
<td>7.21±0.34</td>
<td>8.06±0.48</td>
</tr>
<tr>
<td>4</td>
<td>6.59±0.46</td>
<td>8.14±0.68</td>
<td>7.44±0.34</td>
</tr>
<tr>
<td>5</td>
<td>8.61±0.68</td>
<td>8.10±1.32</td>
<td>9.23±0.36</td>
</tr>
<tr>
<td>7</td>
<td>9.10±0.33</td>
<td>10.06±0.94</td>
<td>14.27±0.55</td>
</tr>
<tr>
<td>9</td>
<td>9.70±0.25</td>
<td>12.25±0.66</td>
<td>12.72±4.05</td>
</tr>
<tr>
<td>11</td>
<td>10.32±0.60</td>
<td>13.62±0.87</td>
<td>17.28±1.59</td>
</tr>
<tr>
<td>14</td>
<td>10.35±0.31</td>
<td>18.62±1.37</td>
<td>18.43±0.96</td>
</tr>
<tr>
<td>17</td>
<td>11.62±0.21</td>
<td>19.62±1.62</td>
<td>21.48±1.40</td>
</tr>
<tr>
<td>20</td>
<td>11.36±0.71</td>
<td>18.77±1.97</td>
<td>24.29±1.77</td>
</tr>
<tr>
<td>23</td>
<td>12.96±0.58</td>
<td>22.10±3.02</td>
<td>26.05±0.96</td>
</tr>
<tr>
<td>27</td>
<td>14.65±0.86</td>
<td>24.84±3.63</td>
<td>32.28±2.19</td>
</tr>
<tr>
<td>31</td>
<td>17.22±1.27</td>
<td>27.47±4.11</td>
<td>33.72±3.67</td>
</tr>
<tr>
<td>35</td>
<td>21.61±1.31</td>
<td>33.88±5.92</td>
<td>36.17±2.35</td>
</tr>
<tr>
<td>39</td>
<td>23.33±1.03</td>
<td>34.66±5.40</td>
<td>37.19±3.16</td>
</tr>
</tbody>
</table>
Day 3: In specimens of 34ºC, the pterygiophores have developed, the proximals partly ossified but the distals were cartilaginous. In 22 and 28ºC treatments, the dorsal fin skeletal structures were invisible.

Day 4: In specimens of 34ºC, the pterygiophores were developed, the proximals partly ossified and bent but the distal elements were cartilaginous. In specimens of 28ºC, the pterygiophore cartilaginous elements (distal and proximal) have developed, but in 22ºC treatment, the dorsal fin skeletal structures were invisible.

Day 7: In specimens of 34ºC, the proximals mostly ossified and widened, and the distals were ossified. In specimens from 28ºC, the pterygiophores were cartilaginous, but in those of 22ºC treatment, the dorsal fin skeletal structures were invisible.

Day 9: In 34ºC treatment, the proximal and distal elements were ossified and stay was visible. In specimens from 28ºC, the pterygiophores were cartilaginous, but in 22ºC treatment, the dorsal fin skeletal structures were invisible.

Day 11: In specimens of 34ºC, all dorsal fin elements were ossified attaching together strongly and stay was still cartilaginous. In specimens of 28ºC, cartilaginous elements (distal and proximal) have appeared. In 22 and 28ºC treatments, the dorsal fin skeletal structures were invisible.

Day 14: In specimens from 34ºC, the proximal and distal elements were ossified. In specimens from 28ºC, the pterygiophore cartilaginous elements (distal and proximal) have developed, but in 22ºC treatment, the dorsal fin skeletal structures were invisible.

Day 17: In specimens from 34ºC, the proximal and distal elements were ossified and stay was visible. In specimens from 28ºC, the pterygiophores were cartilaginous, but in those of 22ºC treatment, the dorsal fin skeletal structures were invisible.

Day 21: In specimens of 34ºC, all dorsal fin elements were ossified attaching together strongly and stay was still cartilaginous. In specimens of 28ºC, cartilaginous elements (distal and proximal) have appeared. In 22 and 28ºC treatments, the dorsal fin skeletal structures were invisible.

Fig. 1. Overview of the developmental stages of the dorsal fin elements of Nile tilapia Oreochromis niloticus larvae in 34ºC.
in anterior part of fin, the proximal and distal elements were partly ossified and in posterior part, the distal and proximal elements were cartilaginous, but in 22ºC treatment, the dorsal fin skeletal structures are invisible.

Day 14: In 34ºC treatment, the dorsal fin elements were completed with appearance of the supraneural, as the last element in the anterior part of fin and stay element was cartilaginous. In specimens of 28ºC, the proximal mostly ossified and distal completely ossified; in 22ºC treatment, the dorsal fin skeletal (proximal and distal) structures were cartilaginous and visible.

Day 17: In 34ºC treatment, the dorsal fin elements were similar to that of day 14, and until the end of the experiment, with the growth of the fish were widened. In 28ºC, the proximal mostly ossified and extremely attached to the distal elements. In 22ºC treatment, the dorsal fin skeletal structures were cartilaginous.

Day 21: In 28ºC, the proximal mostly ossified and extremely attached to distal elements. In 22ºC treatment, the dorsal fin skeletal structures were cartilaginous.

Day 24: In 28ºC, the stay was visible. In 22ºC treatment, the dorsal fin skeletal structures were cartilaginous.

Day 27: In 28ºC, the stay was still cartilaginous and supraneurals in the anterior part of the fin was visible. In 22ºC treatment, the dorsal fin skeletal
structures were partly ossified but mostly cartilaginous.

Day 31: In 28°C, the dorsal fin elements were similar to that of day 27 and with fish growth, the skeletal elements were widened. In 22°C treatment, the dorsal fin skeletal structures were mostly ossified but partly cartilaginous.

Day 35: In 28°C, the dorsal fin elements were similar to day 27 and until the end of the experiment, with the growth of the fish were widened. In 22°C treatment, the dorsal fin skeletal structures were mostly ossified and stay element was visible and cartilaginous.

Day 39: In 22°C treatment, the dorsal fin skeletal structures were ossified, stay was cartilaginous and supraneural appeared; the dorsal-fin elements were completed.

**Anal fin development (Figs. 1-6)**

Day 0-1: No anal fin skeletal structures were visible.

Day 2: In specimens from 34°C, the pterygiophore cartilaginous elements (distal and proximal) have appeared. In 22 and 28°C treatments, the anal-fin skeletal structures were invisible.
Day 3: In specimens from 34°C, the proximal elements were partly ossified and widened but distal elements were cartilaginous. In 22 and 28°C treatments, the anal-fin skeletal structures are invisible.

Day 4: In 34°C specimens, the proximals were mostly ossified and widened but distal elements were cartilaginous. In 28°C treatment, the anal-fin skeletal cartilaginous structures (proximal and distal elements) were appeared; but no anal-fin skeletal structures were visible in 22°C.

Day 5: In 34°C specimens, the proximal elements were mostly ossified and widened but distal elements were cartilaginous. In 28°C treatment, the anal-fin skeletal structures (proximal and distal elements) were cartilaginous; but no anal-fin skeletal structures were visible in 22°C.

Day 7: In 28 and 34°C treatments, the anal-fin elements were mostly similar to day 5 and no anal-fin skeletal structures were visible in 22°C.

Day 9: In 34°C specimens, the proximal elements were more ossified; distal elements and anal-fin structures in 28°C were cartilaginous, and anal-fin structures were invisible in 22°C.

Day 11: In 34°C specimens, the anal-fin structures were similar to day 9; anterior proximal elements were partly ossified, posterior proximal elements and distal elements in 28°C were cartilaginous, and anal-fin cartilaginous structures were still invisible in 22°C.

Day 14: In 34°C, the stay was appeared and three anterior proximal were completely ossified, other structures were similar to day 9; these structures were preserved until end of study; the proximal and distal elements were mostly ossified in 28°C, and in 22°C anal-fin structures were cartilaginous.

Day 17: In 28°C, the proximal and distal elements were similar with those of day 14 but widened, and in 22°C, the anal fin structures were cartilaginous and similar to day 14.

Day 21: In 22 and 28°C treatments, the proximal and distal elements were similar to those of day 17.

Day 24: In 28°C, the stay was appeared and anal-fin elements were similar to day 21 and not changed till end of study; In 22°C treatment, the anal-fin elements were unchanged from day before, but widened.

Day 27: In 22°C, the anterior three pterygiophore were partly ossified and other elements remained cartilaginous.

Day 31: In 22°C, the anterior three pterygiophore were mostly ossified and the proximal elements were partly ossified but distal element were cartilaginous.

Day 35: In 22°C, the anterior three pterygiophore were mostly ossified and the proximal elements mostly ossified distal element cartilaginous.

Day 39: In 22°C, the anterior three pterygiophore were completely ossified and proximal elements mostly ossified but distal element cartilaginous and stay was appeared.
Day 0 (hatch day): No caudal fin skeletal structures were visible.

Day 1: In 34°C, the caudal-fin cartilaginous elements include three hypural, rudimentary neural arch, last neural spine and last hemal spine have appeared. But in 22 and 28°C treatments, the caudal fin skeletal structures were invisible.

**Fig. 7.** Overview of the developmental stages of the caudal fin elements of Nile tilapia *Oreochromis niloticus* larvae in 34°C.

**Fig. 8.** Overview of the developmental stages of the caudal fin elements of Nile tilapia *Oreochromis niloticus* larvae in 28°C.

**Caudal fin development (Figs.7-9)**

Day 0 (hatch day): No caudal fin skeletal structures were visible.

Day 1: In 34°C, the caudal-fin cartilaginous elements include three hypural, rudimentary neural arch, last neural spine and last hemal spine have appeared. But in 22 and 28°C treatments, the caudal fin skeletal structures were invisible.
Day 2: In specimens from 34ºC, number of the hypurals were increased, first marker of the urostyle, preural 1-2 have appeared, and these elements were cartilaginous. A number of the hypurals were appeared in 28ºC. In 22ºC treatments, the caudal fin skeletal structures were invisible.

Day 3: In this age, the caudal fin skeleton in specimens from 34ºC was completed and ossified, therefore the preural 1-2, urostyle and rudimentary neural arch were completely ossified and other elements partly ossified. The specimens of 28ºC, have the cartilaginous neural spine, rudimentary neural arch, epural, hypurals, parhypural and hemal spine and partly ossified urostyle and preurals 1-2. In 22ºC treatments, the caudal fin skeletal structures were invisible.

Day 4: Caudal fin skeleton in specimens of 34ºC, the preural 1-2, urostyle and rudimentary neural arch were similar to day 3 and half of other elements were ossified. In the specimens of 28ºC, the urostyle and preurals 1-2 were ossified and others were cartilaginous. In 22ºC treatments, the caudal fin skeletal structures were invisible.

Day 5: In 34ºC, the preural 1-2, urostyle and rudimentary neural arch were similar to day 3 and other elements were mostly ossified. In specimens of 28ºC, the neural arch or neural spine, rudimentary neural arch, epural, hypurals, parhypural and hemal spine were partly ossified. In 22ºC treatments, the caudal-fin skeletal structures were invisible.

Day 7: In 34ºC, the preural 1-2, urostyle and rudimentary neural arch were similar to day 3 and other elements were mostly ossified. In specimens of 28ºC, half of the caudal fin skeleton were ossified. In 22ºC treatments, the caudal fin skeletal structures include neural and hemal spine, hypurals and hypurals and Fig. 9. Overview of the developmental stages of the caudal fin elements of Nile tilapia Oreochromis niloticus larvae in 22ºC.
parhypural were appeared.

Day 9: In 34ºC, amount of ossification of elements were more than before. In specimens of 28ºC, the caudal fin skeleton was mostly ossified. In 22ºC treatments, number of the caudal-fin skeletal structures were increased and all of them were cartilaginous.

Day 11: In 34ºC, ossification and growth of the caudal-fin elements were completed and do not change until end of experiment. In 28ºC, the caudal fin skeleton was mostly ossified, more than before. In 22ºC treatments, number of the caudal-fin skeletal structures were equal with day 9 but widened.

Day 14: In specimens of 28ºC, the caudal-fin skeleton was mostly ossified. In 22ºC treatments, number of the caudal fin skeletal structures were completed but all of them were cartilaginous excluding the preural1-2 and urostyle that centrally little ossified.

Day 17: Caudal fin skeleton in specimens of 28ºC, were almost similar day 14; and the caudal fin skeleton of the specimens of 22ºC treatment, compared to day 14 not changed.

Day 21: Caudal fin skeleton in specimens of 28ºC were completed; in 22ºC specimens, amount of ossification of the preurals and urostyle increased but other elements showed no distinctive change.

Day 24: In 22ºC specimens, the preurals and urostyle were mostly ossified and other elements had no distinctive change, and were cartilaginous.

Day 27: In 22ºC specimens, ossification in preurals and urostyle were completed and other elements were partly ossified.

Day 31: in 22ºC specimens, ossification amount in caudal-fin elements were similar to those of day 27.

Day 35: The neural and hemal spines, rudimentary neural arch, epurals, hypurals and parhypural were mostly ossified, increasing their size.

Day 39: Ossification in most elements of the the caudal fin completed and posterior edge of the hypurals 1-4 and parhypural remained cartilaginous.

**Vertebral column development (Figs. 10-12)**

Day 0 (hatch day): No vertebral column structures are visible.

Day 1: In 34ºC, the hemal and neural spine as thin line were appeared and the notochord segmentation has not occurred. In 28ºC specimens, the notochord without segmentation was obvious but no spins and in 22ºC treatment nothing was visible.

Day 2: Neural and hemal spines were larger and the notochord was segmented in 34ºC specimens. In 28ºC, tiny neural and hemal spines in caudal part of the body was visible but no element in 22ºC was
Day 3: In 34°C, the vertebral column was completely ossified and the neural and hemal spines were partly ossified. Notochord were segmented and neural and hemal spines were bigger in 28°C. In 22°C, the notochord or spines were invisible.

Day 4: In 22°C, the notochord were appeared but no hemal or neural spines. In 28°C, segmentation and ossification of the vertebrate column were completed and spines were widened. In 34°C, space between caudal peduncle vertebrate were obvious and other part were similar to before this day.

Day 5: In 34°C, the ventral ribs were appeared in this age. Hemal and neural spines in 28°C were partly ossified and in 22°C, the spines were appeared.

Day 7: In specimens of three treatments in this age, big change did not happen.

Day 9: Number of the ventral ribs were increased and intramuscular spines were appeared in 34°C. In 28°C, the ventral ribs were appeared and neural and hemal spines in 22°C were widened.

Day 11: In 34°C, ossification in neural and hemal spines, vertebrates and intramuscular spines were completed and number of the intramuscular spines increased. Number and size of the ventral ribs in 28°C increased and 22°C specimens had no obvious change.

Day 14: Axial skeleton in 34°C was similar with day 11 and do not change until end of experiment; in 28°C, number of the ventral ribs increased and intramuscular spines were appeared. Segmentation in the notochord started and the caudal peduncle vertebra were partly ossified in 22°C.

Day 17: Most of elements in 28°C were completely ossified excluding edge of the ventral ribs; and no distinctive change happened in 22°C specimens.

Day 21: In 28°C, growth of elements is followed and caudal peduncle vertebra were mostly ossified. The ventral vertebrae were partly ossified, ventral
ribs appeared and hemal and neural spines widened in 22°C.

Day 24: Number of the intramuscular spines in 28°C increased; in 22°C, the vertebrae were mostly ossified, ventral ribs ossified and hemal and neural spines partly ossified.

Day 27: It seems that the axial skeleton ossification in 28°C was completed. In 22°C, the vertebrae were completely ossified, and spines partly ossified.

Day 31: In 22°C, number of the ventral ribs increased that were ossified, half of spines were also ossified, and intramuscular spines were appeared.

Day 35: In 22°C neural and hemal spines were mostly ossified, number of intramuscular spines increased.

Day 39: All elements of the axial skeleton were ossified and ossification in were complete.

**Discussion**

This study aimed firstly to describe the larval osteological development including unpaired fins, caudal complex and vertebral column in Nile tilapia, *Oreochromis niloticus*, and secondly, to examine the effects of different rearing temperatures (22, 28 and 34°C) on the onset and end of each osteological developmental stages. Before identifying the responsible factors for the initiation of skeletal deformity, recognizing the common patterns of skeletal development is necessary (Gavaia et al. 2002). In addition, chondrogenesis and ossifications patterns were investigated using double staining method (alizarin red-alcian blue). The using of double staining method to examine developmental stages of cartilage and bone structures allows the visualizing of the entire skeleton during vertebrate development and identifying of any deformities that may occur (Gavaia et al. 2002).

The results showed that chondrogenesis and ossifications in different temperature treatments starts at different ages (or total length). Development of the dorsal, anal, caudal fins and axial skeleton in 22°C begins at 14 (10.35±0.31mm SL (standard length)), 14 (10.35±0.31mm SL), 7 (9.10±0.33mm

---

**Fig. 12.** Overview of the developmental stages of the vertebral column elements of Nile tilapia *Oreochromis niloticus* larvae in 22°C.
SL) and 5 (8.61±0.68mm SL) DPH, respectively; in 28ºC, they begins on 4 (8.14±0.68mm SL), 4 (8.14±0.68mm SL), 2 (5.89±0.15mm SL) and 2 (5.89±0.15mm SL) DPH, respectively and in 34ºC, begins at 2 (7.39±0.43mm SL), 2 (7.39±0.43mm SL), 1 (5.79±0.42mm SL) and 1 (5.79±0.42mm SL) DPH, respectively.

The caudal-fin of Senegal sole (*Sole senegalensis*) is the first to develop, followed by anal and dorsal and then paired fins (Gavaia et al. 2002). This same sequence of fin development has also been observed in the Nile tilapia in the current study.

Campinho et al. (2004) showed that the effect of temperature on chondrogenesis in *O. mossambicus* did not appear to coincide with that discussed for events such as hatching, notochord flexion and growth.

Although chondrogenesis is began at 32ºC earlier, it was substantially completed at a later when compared to the optimum culture temperature of 27ºC. With the exception of some skeletal structures in the larvae at 22ºC, it seems that the sequence in which entire regions initiated and terminated chondrogenesis to be relatively well-conserved.

Campinho et al. (2004) suggested that elements of the dorsal, anal and pelvic fins that involved in improvement of maneuverability, completed chondrogenesis at the transition from the larval to juvenile stage. A more detailed analysis of the chondrogenesis and ossification sequences in each skeletal region (e.g. dorsal, anal, caudal fins and axial skeleton) reveals that the order and sequences of appearance of the elements of each region was conserved regardless of rearing temperature, this study results were coinciding with Campinho et al. (2004).

The effect of a reduction in rearing temperature (22ºC vs. 28 and 34ºC) on chondrogenesis and ossification stages in *O. niloticus* is severe; all studied structures began to cartilage formation and ossification too late and they completed chondrogenesis and ossification stages in end of study period, while specimens in 28 and 34ºC began and completed these stage soon rather than 22ºC. Part of the effects of low temperature can be associated with delay in start of chondrogenesis, and another part may also be the direct effect of low temperatures on the structure and cycle of the cell (Roubaud et al. 1985; Greene & Selivonchick 1987; Wang et al. 1987; Campinho et al. 2004).

In addition, the results of this study indicate that some skeletal elements (such as supraneural bone in anterior part of dorsal fin or stay element in posterior part of dorsal and anal fins) may provide a complementary index of larval ontogeny in *O. niloticus* and this needs to further study in other species.

It is possible that differences in the degree of bone and cartilage elements development denoting that the ontogeny of the skeleton structures was more linked to larval size than their age. Although, ecologists and some studies frequently use length (total or standard length) as an index of developmental states (Gavaia et al. 2002; Faustino 2002; Campinho et al. 2004; Roo et al. 2010; Hasanpour et al. 2016). However, considerable debates exist in ecological and aquaculture studies about the most reliable metric with which to assess developmental status of different tissues or organs.

Acknowledgments

The authors would like to express their sincere gratitude to F. Kermani and E. Ebrahimi for their help in maintenance of the fish. This study was financially supported by Isfahan University of Technology.

References


Barón‐Aguilar, C.C.; Rhody, N.R.; Brennan, N.P.; Main,


مقاله پژوهشی

**Oreochromis niloticus** (Teleostei: Cichlidae) تنوع بررسی اثرات دما بر نمو اسکلتی در

مظهر زمانی فرادنبه، یزدان کیوانی

دانشکده منابع طبیعی (گروه شیلات)، دانشگاه صنعتی اصفهان، اصفهان، ایران.

چکیده:
نمو ساختارهای غضروفی و استخوانی در بالهای پشتی، مخرجی و دمی و ستون فقرات در ماهی تیلاپیای نیل (Oreochromis niloticus) تحت تأثیر سه تیمار دمایی (22، 28 و 34 درجه سانتی‌گراد) بررسی شد. نمونه‌های ماهی به طور دوره‌ای در طول مرحله نموی از روز تخم‌گذاری تا 99 روز بعد از تخم‌گذاری جمع‌آوری شدند. نمو ساختارهای غضروفی و استخوانی ارزیابی شد. نتایج نشان داد که الگو و ترتیب نمو و ظهور این ساختارها در سه تیمار مشابه بوده و نتایج در زمان‌نگاره طوری است که ساختارهای غضروفی و استخوانی در نمونه‌های تیمار 34 درجه شروع و پایان زودهنگامتر از نمونه‌های دیگر تیمارهای دیگر شد. دما بر شروع و پایان غضروفی و ساختارهای استخوانی تأثیر گذار بود. این تأثیر در تیمار 22 درجه نسبت به دو تیمار دیگر سخت بود. ترتیب فرایند غضروفی و استخوانی در سه تیمار مشابه بود.

کلمات کلیدی: نمو، اسکلت، غضروف، استخوان، آنتوژنی.