Chapter 10
High Water Temperature Induces Jaw Deformity and Bone Morphogenetic Protein (BMP) Gene Expression in Golden Pompano *Trachinotus ovatus* Larvae

Jing Sun, Zhengyi Fu, Zhenhua Ma, and Gang Yu

Abstract Deformity during the early development of golden pompano *Trachinotus ovatus* has significantly influenced the production capacity of a fish hatchery. However, factors leading to skeletal deformity in this species have never been assessed. In this chapter, the impact of rearing temperature on jaw deformity and BMP gene expression is discussed. Jaw deformity rate of fish larvae increased with the increase of ambient temperature, and the highest malformation rate was recorded at 33 °C. The expressions of the BMP4 and BMP5 genes were positively correlated to the occurrence of jaw malformation. The cultivating water temperature of *T. ovatus* larvae should be maintained at 26–29 °C. These findings will clarify the role of water temperature in influencing bone deformity in fish larvae and provide a reference point to optimize the environmental condition during the rearing process of golden pompano in hatcheries.

Keywords *Trachinotus ovatus* larvae · Water temperature · Jaw deformity · BMPs

10.1 Introduction

Temperature is one of the important factors affecting the early development of larval fish through regulating the feeding behavior and metabolism during larval development (Ma 2014; Kestemont and Baras 2001). Besides, studies have shown that unsuitable temperature can cause high mortality and deformity of larval fish (Lein et al. 1997; Ørnsrud et al. 2004; Ludwig and Lochmann 2009). The skeletal malformation is often related to slow growth and high mortality of fish larvae and has continually hindered the production of marine fish in the hatchery (Koumoundouros 2010; Boglione et al. 2013a, b). Jaw abnormality is not only a

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factor leading to a high mortality rate of fish but also a factor reducing the market value of fish (Cobcroft et al. 2004; Barahona-Fernandes 1982; Ma et al. 2014c). Such malformations have been reported in commercial aquaculture of gilthead sea bream *Sparus aurata* (Prestinicola et al. 2013; Andrades et al. 1996), striped trumpeter *Latris lineata* (Cobcroft et al. 2012), and yellowtail kingfish *Seriola lalandi* (Cobcroft et al. 2004). Lein et al. (1997) suggested that unsuitable rearing temperature can cause jaw malformations in fish. Under inappropriate temperature, significant deformities of skeleton and gill cover have been reported in gilthead seabream *Sparus aurata* and cranial malformation in European sea bass *Dicentrarchus labrax* (Georgakopoulou et al. 2007). In pompano *Trachinotus ovatus*, more than 33% of fish in the same cohort display more than one type of deformities during the larval stage (Zheng et al. 2014; Ma et al. 2014c), but it is not clear whether the temperature can cause jaw malformations in this species. Consequently, in the process of pompano's larval ontogenesis, to study relationship between temperature and the jaw malformation is very necessary.

Skeletogenesis includes differentiation and proliferation of various cell types, such as osteoblasts, chondrocytes, osteoclasts, and osteocytes which determine the shape, size, and mineral composition of bone structure (Karsenty and Wagner 2002; Nijweide et al. 1986; Phan et al. 2004). The expression of genes mainly underlies the procedure of cell proliferation and differentiation but could also be changed by individual genetic characteristics and biological and nonbiological elements (Boglione et al. 2013a, b). Therefore, it is necessary to examine the structure of gene networks, which will provide an insight into the understanding of the underlying mechanisms of bone deformity. The biological and nonbiological factors could cause bone malformation, while the gene expression is the potential mechanism behind this factor. In some vertebrates, bone formation is controlled by bone morphogenetic proteins (BMPs) at different phases of cell development (e.g., maturing osteoblast, stem cells, hypertrophic chondrocytes, proliferative chondrocytes) (Hogan 1996a, b; Windhausen et al. 2015; Alaee et al. 2014). In the animal kingdom, the function and structure of BMPs are conservative. The function and structure of different BMPs in single species can be seen through their roles in various biological processes (Razdorov and Vukicevic 2012). For example, BMPs 1, 2, and 3 play an essential role in bone fracture repair because these proteins can stimulate the growth of osteoblasts (Grgurevic et al. 2011). BMPs 2, 4, and 6 can regulate skeletogenesis, in particular, chondrocyte differentiation into cartilage, and cell maturation in osteoblast lineages can lead to bone formation (Minina et al. 2001; Rickard et al. 1994; Wan and Cao 2005; Canalis et al. 2003). Although several studies have been conducted to test the expression of BMP genes in various fish species, most of these studies are focused on the changes during embryonic development (Myers et al. 2002; Palomino et al. 2014; Marques et al. 2014, 2015; Tiago et al. 2014). In marine fish, the studies on the expression of BMP genes after incubation and their biological function are limited to the test of nutrient effect such as lipids and vitamins (Villeneuve et al. 2005a, b, 2006). Recently, BMP genes have been used to evaluate the impact of high temperature on the bone abnormality of fish larvae (Ytteborg et al. 2010). The study on BMP expressions in the ontogeny of golden pompano can contribute to the baseline data on the factors relevant to jaw deformity in fish larvae during osteogenesis.

The *T. ovatus* is an important economic species of the Carangidae family and is a potential species for aquaculture diversification (Guo et al. 2014). Although the digestive function develops early (Ma et al. 2014a, b) and the nutrient requirements of the first feeding *T. ovatus* larvae have been researched (Ma et al. 2014d), the information on the cause of deformity during the early developmental period is fragmental. Our previous studies have reported the type, position, and frequency of jaw and skeletal deformities in hatchery-reared *T. ovatus* larvae (Zheng et al. 2014; Ma et al. 2014c). However, factors leading to skeletal deformity in this fish have never been assessed. In this chapter, the impact of rearing temperature on jaw deformity and BMP gene expression is discussed. The results are derived from fish cultured at three constant temperatures of 26, 29, and 33 °C from hatching to 18 days post-hatch (DPH) in a hatchery.

10.2 Growth, Survival, and Jaw Deformity at Different Temperatures

The water temperature is a key to the success of fish hatchery production factors and can significantly impact the quality of fish larvae (Boglione et al. 2013b). The growth of *T. ovatus* larvae was significantly affected by temperature ($P < 0.05$, Fig. 10.1). The specific growth rates (SGRs) of fish increase with temperature elevation in the rearing facility. Temperature can affect metabolism, food intake, and growth of fish (Ma 2014; Jobling 1994), and the effect of temperature on larval growth of farmed fish species has been well documented including striped trumpeter *Latris lineata* (Choa et al. 2010), Australian snapper *Pagrus auratus* (Fielder et al. 2005), nase *Chondrostoma nasus* L. (Keckeis et al. 2001), yellowtail kingfish *Seriola lalandi* (Ma 2014), and haddock *Melanogrammus aeglefinus* L. (Martell et al. 2005). In *T. ovatus*, the rapid growth at high temperature probably is related to the high food intake and improved digestive mechanism as evidenced by the early appearance of gastric glands and goblet cells in the gut after 15 DPH at 27–29 °C (Ma et al. 2014b). The growth of fish larvae was expedited when fish were weaned from rotifers to *Artemia* nauplii. Like Florida pompano *Trachinotus carolinus* (Riley et al. 2009), the mouth gape of *T. ovatus* larvae reached 1.05 mm by 12 DPH, which enables the fish to ingest larger food particles such as *Artemia* nauplii. For this reason, the marked size difference in *T. ovatus* size between temperature treatments at 18 DPH may also be attributed to the use of enriched rotifers for high-calorie food from 9 DPH onward.

In both artificial and wild environments, fish will go through critical periods in ontogeny and shift from endogenous nutrition to exogenous nutrition (Otterlei et al. 1999; Ma et al. 2012). During the phase of feed transformation, when food provision and light condition are within the range of first feeding requirement for fish larvae,

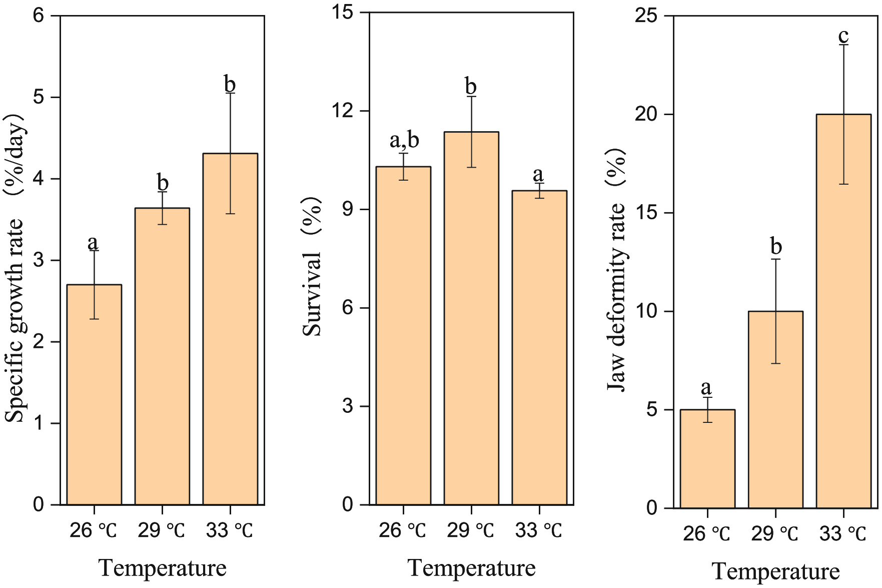

Fig. 10.1 Survival, specific growth rate, and jaw deformity rate of *T. ovatus* larvae cultured at 26, 29, and 33 °C. Means with the same letter are not significantly different ($P > 0.05$) (the symbol of "°C" is not shown in the *x*-axis of the figure) (Ma et al. 2016)

the temperature may be the most decisive factor for fish survival (Kamler 1992; McGurk 1984; Ma 2014; Gardeur et al. 2007). Previous research has indicated that mortality is temperature-dependent in the larvae and juveniles of *Pangasianodon hypophthalmus* (Baras et al. 2011), *Seriola lalandi* (Ma 2014), *Glyptocephalus cynoglossus* (Bidwell and Howell 2001), and *Inimicus japonicus* (Wen et al. 2013). Ma (2014) argues that there is a temperature-sensitive stage when mortality occurs in fish larvae during early development. In *T. ovatus*, the lowest survival rate was found when fish were reared at 33 °C (Fig. 10.1), suggesting that the highest level of temperature tolerance has reached for this species.

Jaw abnormality is a crucial point in fish culture because it impacts the quality of fingerlings for further grow-out (Von Westernhagen 1988). In *T. ovatus*, the rate of jaw deformities rose with the rise of temperature, and the maximum value occurred at 33 °C (Fig. 10.1). The temperature-dependent deformity has also been reported in other species such as Pacific herring *Clupea pallasi* (Alderdice and Velsen 1971) and Atlantic halibut *Hippoglossus hippoglossus* (Lein et al. 1997). The fast growth at temperature requires a high level of dissolved oxygen (Rombough 1997) and an adequate amount of nutritional supply. However, unless the feed contains high levels of energy, the fish may not grow very fast (Cahu et al. 2003a, b; Ma 2014). In addition, temperature could interfere with fish development by accelerating or postponing the development of the digestive system, which may be related to the increased rate of skeletal malformation at high temperature. In the present study, the fertilized eggs of *T. ovatus* hatched at 26 °C, and then yolk sac larvae were acclimated to each of the experimental temperatures (26, 29, and 33 °C) for 5 h on 2 DPH. However, the rapid augment of ambient temperature from 26 to 29 °C or 33 °C may also induce jaw malformation.

10.3 Expression of BMP Genes at Different Temperatures

The growth of bone depends on the dynamic balance between the rate of cartilage generation and bone adherence (Breur et al. 1991). BMP2 and BMP4 genes are closely associated with protein synthesis for physiological activities in the crucial period of embryonic development, such as dorsal-ventral axis specification (Graff 1997), apoptosis (Glozak and Rogers 1996; Graham et al. 1994; Zou and Niswander 1996), and epithelio-mesenchymal interactions (Vainio et al. 1993). The BMP2 gene in zebra fish is correlated to the induction and maintenance of ventrolateral cells during the initial stage of development. However, a missense mutation of the BMP2b gene lead to the dorsalized phenotype of the zebra fish *swirl* mutant, which lacks the cardiogenic mesoderm (Kishimoto et al. 1997). Ytteborg et al. (2010) found that the expression of BMP2 increased when fish are under a high temperature condition. In *T. ovatus*, the expression of BMP2 was significantly affected by water temperature ($P < 0.05$, Fig. 10.2). Compared with the fish at 26 °C, the expression of BMP2 in fish showed a trend of increase at 29 °C (Fig. 10.2), which is consistent with the result reported by Ytteborg et al. (2010). However, the reason for low expression of BMP2 in fish at 33 °C remains unclear.

BMP4 plays a different role in the growth of some vertebrate species (Whitman 1998; Hogan 1996b; Dale and Johns 1999; Mehler et al. 1997; Shi and Massague 2003) and has been used to assess whether the BMP pathway is involved in nutrient deficiency of bone deformities (Villeneuve et al. 2005a, b, 2006) or environmental stress (Ytteborg et al. 2010). According to Villeneuve et al. (2006), the increase of BMP4 and RARγ expressions can diminish the number of osteoblasts for bone generation, and the damage of bone cells is counteracted by the interaction between retinoic acid and BMP4. In *T. ovatus*, the expression of BMP4 at 29 and 33 °C was significantly higher than those at 26 °C. Jaw deformities of fish at 29 and 33 °C were also significantly higher than those fish at 26 °C. This result is consistent with Ytteborg et al. (2010), such as the results of the study, namely, under the condition of high temperature raising, tend to increase the BMP4 gene expression. When the expression of BMP4 gene was upregulated, the incidence of jaw deformity increased (Villeneuve et al. 2006).

Previous studies have demonstrated that the 60A subgroup (BMP5, 6, 7) is functionally supernumerary and that the collective expression of the 60A subgroup determines the functional change in the early fish development (Kim et al. 2001; Solloway and Robertson 1999). During endochondral ossification, BMP5 can stimulate the mesenchymal cells to coagulate into chondrocytes (Bailon-Plaza et al. 1999; King et al. 1994). Moreover, the mutated BMP5 gene can cause skeletal malformations, indicating the essentiality of BMP5 in skeletal development (Storm

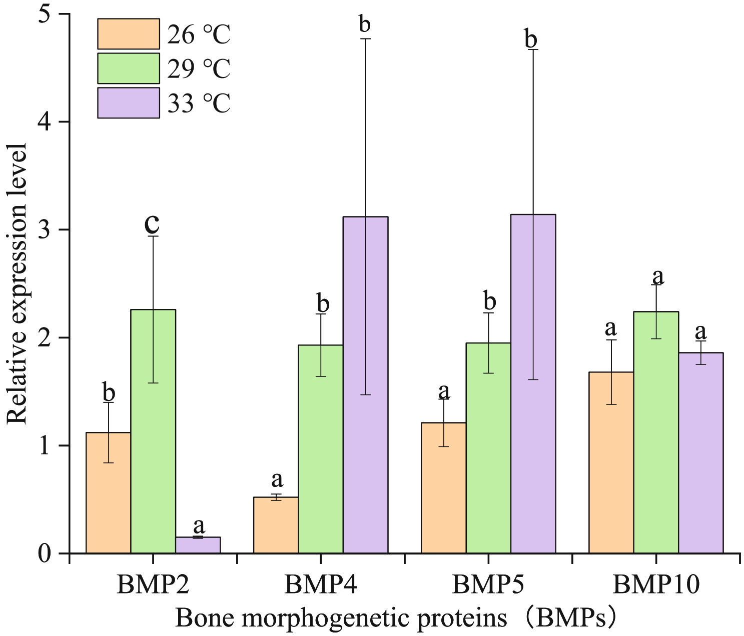

Fig. 10.2 Relative expression levels of bone morphogenetic proteins of *T. ovatus* larvae at different temperatures on 18 DPH. For BMP2, the reference was the 26 °C BMP2; for BMP4, the reference was the 26 °C BMP4; for BMP5, the reference was the 26 °C BMP5; for BMP10, the reference was the 26 °C BMP10. Means with the same letter are not significantly different ($P > 0.05$) (Ma et al. 2016)

et al. 1994; Kingsley et al. 1992; Wolfman et al. 2003). In *T. ovatus*, BMP5 expression patterns in fish is similar to the expression pattern of BMP4 (Fig. 10.2). Under 29 and 33 °C, the expression level of BMP5 in fish was significantly higher than that under 26 °C. Although the expression level of BMP5 and jaw abnormalities in *T. ovatus* increased with the increase of rearing temperature, there is no direct evidence to suggest that the expression of BMP5 can regulate the jaw abnormalities.

The BMP10 gene is mainly expressed in the heart of an adult but with a lower chance in the lung and liver (Neuhaus et al. 1999). During the period of heart development, BMP10 is expressed in the ventricular chamber, atrium, and trabeculae in *Bulbus cordis* (Neuhaus et al. 1999). In zebra fish, a comparatively high BMP10 expression occurs in the liver and heart, but low expression level can be observed in the kidney and brain (Bland 2001). In *T. ovatus*, feeding temperature had no significant effect on the expression of BMP10, indicating that 18 DPH was insensitive to the expression of BMP10 in ovate cells.

10.4 Conclusion

In summary, temperature significantly regulated the jaw development in larval *T. ovatus*. Jaw malformation rate in fish larvae increased with the increase of rearing temperature, and the highest malformation rate occurred in fish at 33 °C. To reduce massive malformation, we should control the rearing water temperature at 26–29 °C for *T. ovatus* larvae. Gene expression analysis indicates that the expression levels of BMP4 and BMP5 were positively correlated to the occurrence of jaw malformations, but the underlying mechanism needs further study.

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