Transfer of maternal immunity using a polyvalent vaccine and offspring protection in Nile tilapia, *Oreochromis niloticus* [version 4; peer review: 2 approved, 1 approved with reservations]

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Abstract

Background

Vaccination is an effective and alternative means of disease prevention, however, it cannot be conducted on the offspring of fish. For this process to take place, the transfer of maternal immunity should be implemented. This study aims to determine the effectiveness of transferring immunity from the broodstock to the offspring using a polyvalent vaccine against *Aeromonas hydrophila*, *Streptococcus agalactiae*, and *Pseudomonas fluorescens* in Nile tilapia, *Oreochromis niloticus*.

Methods

Nile tilapia broodstock with an average weight of 203g (±SD 23) was reared in spawning ponds until mass spawning and harvested one week post-spawning for vaccination. After being vaccinated according to the treatment, each fish broodstock was reared in 3x3 m cages installed in an earthen pond with a density of 20 broodstock, consisting of 15 females and 5 males. The vaccine used was a...
formalin-killed whole-cell vaccine at a density of 10^10 cfu/mL injected intramuscularly (i.m.) at a dose of 0.4 mL/kg fish. Nile tilapia was injected with a vaccine used as a treatment. Example include *A. hydrophila* monovalent (MA), *S. agalactiae* monovalent (MS), *P. fluorescens* monovalent (MP), *A. hydrophila* and *S. agalactiae* bivalent (BAS), *A. hydrophila* and *P. fluorescens* bivalent (BAP), *P. fluorescens* and *S. agalactiae* bivalent (BPS), and *A. hydrophila*, *S. agalactiae*, and *P. fluorescens* polyvalent vaccines (PAPS). While the control was fish that were injected with a PBS solution. The broodstock's immune response was observed on the 7th, 14th, 21st, and 28th days, while the immune response and challenge test on the offspring was conducted on the 10th, 20th, 30th, and 40th day during the post-hatching period. The parameters observed consisted of total leukocytes, phagocytic activity, antibody titer, lysozyme, and relative survival percentage (RPS).

**Result**

The application of PAPS in broodstock could significantly induce the best immune response and immunity to multiple diseases compared to other treatments. The RPS of the PAPS was also higher than the other types of vaccines. This showed that the transfer of immunity from the broodstock to the Nile tilapia offspring could protect it against bacterial diseases such as *A. hydrophila*, *S. agalactiae*, and *P. fluorescens*.

**Conclusion**

The application of polyvalent vaccine *A. hydrophila*, *S. agalactiae*, *P. fluorescens* vaccines increased the broodstock's immune response and it was transferred to their offspring. Polyvalent vaccines derived from maternal immunity can protect offspring from disease up to 30 days of age. They were able to produce tilapia seeds that are immune to diseases caused by *A. hydrophila*, *S. agalactiae*, and *P. fluorescens*.

**Keywords**

*Aeromonas hydrophila*, bivalent vaccine, monovalent vaccine, *Pseudomonas fluorescens*, *Streptococcus agalactiae*. 
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Introduction

Tilapia was originally considered to be more resistant to bacterial, parasitic, fungus, and viral diseases than other species of cultivated fish. However, they are found to be susceptible to bacterial and parasitic diseases, particularly during the offspring phase. Globally, the control of bacterial disease mostly uses antibiotics that are proven not environmentally friendly. Some common diseases of tilapia found in several Southeast Asian countries including Indonesia are Streptococcus agalactiae, Aeromonas hydrophila, Edwardsiella ictaluri, Flavobacterium columnaris, and Pseudomonas fluorescens infections. In addition to the bacterial disease, a new disease has emerged called Tilapia Lake Virus (TilV) disease whose specific host is tilapia, causing disease outbreaks with high mortality rates in several Southeast Asian countries such as Thailand and Malaysia.

Among the various methods of disease control, vaccination is one of the most effective ways, which is commonly used. The administration of vaccines is meant to produce antibodies that could improve the immunity of tilapia. Unfortunately, they could not be administered to the offspring of fish because the organs that form the immune response are not yet fully developed, therefore they are unable to produce antibodies. Tilapia fry was not able to produce their own immune system at the age of less than 21 days. Immune systems of Xenopus laevis develop within 2 weeks of age, while Indian major carp develop within 3 weeks of age.

An effective solution to the aforementioned issue is the application of maternal immunity transfer. This is the transfer of immunity from broodstock to offspring, by which immunoglobulin (IgM type) are transferred through eggs. Maternal immunity has been shown to improve the fish offspring’s immunity against pathogens in the early phases of their lives.

This process is usually carried out using monovalent vaccines. However, a polyvalent vaccine would be more effective because it could control multiple diseases especially using a formalin-killed vaccine with low production cost compared to other types of vaccines. Though the effectiveness has been known, the application of polyvalent vaccines to confer maternal immunity in offspring has not been extensively investigated, particularly in Nile tilapia (O. niloticus).

The transfer of maternal immunity using polyvalent vaccine for S. agalactiae, Lactococcus garvieae, and Enterococcus faecalis has been studied by Abu-elala et al., and three vaccine strains for S. agalactiae by Nurani et al. The types of bacterial diseases studied in the aforementioned studies are very limited even though Nile tilapia often suffer from them in fish farms and hatcheries. Besides being infected by S. agalactiae, Nile tilapia are often infected by A. hydrophila and P. fluorescens leading to high mortality, including in Indonesia. Therefore, this study aimed to examine maternal immunity transfer using the polyvalent vaccine for S. agalactiae, A. hydrophila, and P. fluorescens (PAPS). It was expected that the broodstock could pass their immunity to their offspring, making them resistant to the three diseases (A. hydrophila, S. agalactiae, and P. fluorescens bacteria), and also the production of tilapia offspring could also be increased. Furthermore, this study aimed to determine the effectiveness of the transfer of immunity induced by PAPS against A. hydrophila, S. agalactiae, and P. fluorescens from the Nile tilapia (O. niloticus) broodstock to their offspring and the protection against S. agalactiae, A. hydrophila, and P. fluorescens infections.

Methods

Experimental animal

Nile tilapia broodstock, obtained from the Ompo Inland Hatchery, Soppeng, Indonesia, with an average weight of 203g (±SD 23) were used as experimental animal. They were kept in spawning ponds (25X30X1.2 LxWxD) and fed ad libitum with pellets that have a protein content of 30% in the mornings and afternoons. Also, 25% of the water was replaced daily. One week after the fish spawned, they were harvested and a large number of Nile tilapia broodstock at gonad developmental stage 2 were obtained.

Vaccine production

Pure isolates of the A. hydrophila, S. agalactiae, and P. fluorescens bacteria were obtained from the Research and Development of Fish Disease Control Installation, Ministry of Marine Affairs and Fisheries, Depok, Indonesia. Vaccine production was carried out by harvesting bacteria aged 24 hours, which were cultured on TSA media. The yields were then put into 100 mL of PBS with a bacterial density of 10^9 cfu/mL measured by the McFarland method. Further, it was killed with formalin according to the results of Amrullah et al. S. agalactiae and P. fluorescens were inactivated in 1% formalin, while A. hydrophila was inactivated with 0.6% formalin. Later, stirred and incubated for 24 hours at 4°C. After 24 hours of incubation, a vaccine safety test was carried out using the sterilization method. Finally, the vaccine was diluted at a dose of 10^6 cfu/mL and was ready to be used for the vaccination of tilapia broodstock.
Vaccine treatments and administration
The vaccine treatments consist of (1) a monovalent vaccine against *A. hydrophila* (MA), (2) a monovalent vaccine against *P. fluorescens* (MP), (3) a monovalent vaccine against *S. agalactiae* (MS), (4) a bivalent vaccine against *A. hydrophila, P. fluorescens* and (BAP), (5) a bivalent vaccine against *A. hydrophila and S. agalactiae* (BAS), (6) a bivalent vaccine against *P. fluorescens and S. agalactiae* (BPS), (7) a polyvalent vaccine against *A. hydrophila, P. fluorescens and S. agalactiae* (PAPS), and (8) the control, fish injected with PBS solution. However, only the female broodstock was vaccinated.

The vaccination method used was intramuscular (i.m.) by injecting between the first and second scales of the dorsal fin and was administered at a dose of 0.4 mL/kg of fish (±0.08 mL/fish). After the fish were vaccinated, a booster with the same dose as the initial vaccination was later administered on the 7th day. The fish were anesthetized using MS-222 (Sigma) before injection.

The gonadal developmental stage 2 fish post-vaccination were reared using 3×3 m cages and installed in dirt ponds 25×30×1.2 (L×W×D). Furthermore, 20 broodstock were reared per cage, consisting of 15 females and 5 males. The fish were fed with pellets at a dose of 4%/day in the morning, at midday, and in the afternoon. The water was replaced daily at a rate of 5%/day. The fish would spawn after being reared for approximately 4 weeks.

Broodstock and larvae immune response
Following vaccinations, the fish’s immune response was observed on the 7th, 14th, 21st, and 28th day by collecting caudal vein blood samples. The immune response parameters were the antibody titer using the direct agglutination method, total leukocyte, phagocytic activity, and lysozyme activities.

Random blood sampling from the offspring was conducted on each treatment group on the 10th, 20th, 30th, and 40th day post-hatching period. Serum was collected by grinding 5 offspring in effendorf tube for 5 µL with PBS-tween at a ratio of 4:1. It was then centrifuged at 6000 rpm. Furthermore, the serum in the second layer of the centrifugation result was harvested and stored at 47°C for 30 minutes to inactivate the complements. It was then stored for agglutination titer and lysozyme activity. The direct agglutination test on both broodstocks and offspring was carried out by adding 25 µL PBS into the microplate from the 1st to 12th wells. A total of 25 µL of test fish serum based on treatment was added to the 1st well (positive control) and 2nd well. Furthermore, multilevel dilutions were carried out starting from the 2nd well to the 11th well, while the 12th well was not added with serum (negative control). Furthermore, 25 µL of whole cell antigen of bacteria *A. hydrophila, S. agalactiae, P. fluorescens* was added to each of the 1st to 12th wells. The microtiter containing antibodies and antigens was then incubated overnight at room temperature and the agglutinating titer was calculated.

Challenge procedures
The offspring challenge test was conducted on the 10, 20, 30, and 40 days after hatching. It was carried out by dividing the fish into 7 groups based on the type of vaccine administered plus one unvaccinated. Challenge tests on all treatments were carried out using three types of pathogenic bacteria; *A. hydrophila, S. agalactiae, and P. fluorescens*. This test was carried out by placing 20 offsprings into containers containing 4 liters of water and then they were immersed for 24 h in water containing pathogenic bacteria at a dose of 2.1×10⁹ cfu/mL according to their relative treatments, each conducted triplicate. To observe the effectiveness of the vaccine, the relative percentage survival (RPS) was calculated on the 14th day post-challenge test.

Data analysis
The data for the specific and non-specific immune response and RPS were analyzed statistically and with Duncan’s test (IBM SPSS Statistic 21; Chicago, IL, USA).

Results
Broodstock total leukocyte and phagocytic activity post-vaccination
In general, the different types of vaccines at each period of post-vaccination had a significant effect (P<0.05) on the broodstock’s total leukocyte (Figure 1), and phagocytic activity (Figure 2). The follow-up test showed that the fish vaccinated with PAPS had the highest total leukocyte (7.56–10.70×10⁶ cell/mm³) and phagocytic activity (8.33–19.33%), followed by those vaccinated with bivalent and monovalent vaccines, while the lowest was found in control (total leukocyte was 7.40–7.86×10⁶ cell/mm³, phagocytic activity was 9.00–9.33%).

Broodstock and offspring agglutination titers
The broodstock’s antibody (Table 1) increased, especially after the booster, except in the unvaccinated fish. After the peak, the broodstock’s immune response remained high up to day 28 even though there was a tendency for it to decrease. All the types of vaccines at each point of time had a significant effect (P<0.05) on the agglutination titer in the broodstock. The Duncan’s follow-up test showed that the vaccinated broodstock had a higher agglutination titer than the unvaccinated fish. Also, the highest significant value was found in the vaccinated fish with PAPS (1.67–6.67), followed by those vaccinated with bivalent and monovalent vaccines, while the lowest was in control (1.33–1.67). Offspring from unvaccinated broodstocks have native immunity; hence, in the agglutination test occurs agglutination, but it is very low and does not show an increase, and has not been able to control infections.

Based on the effect of the vaccine on the broodstock’s immune response, the agglutination titer in the offspring from the vaccinated broodstock at ages 10, 20, 30, and 40 days was higher than unvaccinated (P<0.05). The follow-up test showed that PAPS was more effective in increasing the agglutination titer in the offspring (6.33–3.00) than the bivalent and monovalent vaccines. The results showed that the administration of vaccines in tilapia broodstock had a significant effect on the maternal immunity transfer to the offsprings that were up to 30 days old (Table 2).

Broodstock and offspring lysozyme activity
The lysozyme activity of broodstock vaccinated with PAPS (29.87–103.08 U/mL) was higher than other vaccines, and the
lowest was in broodstock that was not vaccinated (27.65–33.89 U/mL) (P<0.05) (Figure 3). Generally, the offspring from the broodstock vaccinated with PAPS had a higher lysozyme activity (77.81–43.11 U/mL) than those of other treatments (P<0.05) up to the 30th day, the lowest was in the control (20.29–20.24 U/mL). The results showed that the application of PAPS in tilapia broodstock could increase lysozyme activity transferred to the offspring (Figure 4).

**RPS of offspring post-challenge**

Offsprings that were 10, 20, 30, and 40 days old from the vaccinated broodstock had higher RPS than those from the unvaccinated broodstock after being challenged with bacteria. The offsprings from the broodstock that were vaccinated with PAPS had the highest RPS when challenged with 3 bacteria simultaneously (a combination between *A. hydrophila*, *S. agalactiae*, and *P. fluorescens*) (Table 3) up to day 30. The RPS of the offspring vaccinated with PAPS were 86.11% (10 days old), 78.95% (20 days old) and 56.41% (30 days old). The immune response generated through maternal immunity only lasts up to 30 days and in the end, the immune response will be formed by the body of the offspring itself.

**Discussion**

Efforts to produce seeds that are immune to several diseases were the best alternative to increasing Nile tilapia production. Furthermore, PAPSs for *A. hydrophila*, *S. agalactiae*, and *P. fluorescens* were able to improve the broodstock’s immune
Table 1. The agglutination titer in Nile tilapia broodstock after being vaccinated with various types of vaccines (mean±SE). MA: *A. hydrophila* monovalent, MS: *S. agalactiae* monovalent, MP: *P. fluorescens* monovalent, BAS: *A. hydrophila* and *S. agalactiae* bivalent, BAP: *A. hydrophila* and *P. fluorescens* bivalent, BPS: *P. fluorescens* and *S. agalactiae* bivalent, and PAPS: *A. hydrophila*, *S. agalactiae*, and *P. fluorescens* polyvalent vaccines. Values with different superscripts a,b indicate that their corresponding means are significantly different (P<0.05) according to one-way ANOVA followed by Duncan’s test.

| Type of vaccine | Agglutination titer (log2) | Day after vaccinated (day) |
|-----------------|-----------------------------|----------------------------|
|                 |                             | 0  | 7  | 14 | 21 | 28 |
| MA              | 1.67±0.33a                  | 2.00±0.00ab                | 3.33±0.33a | 3.67±0.33c | 3.67±0.33c |
| MP              | 1.67±0.33a                  | 2.67±0.33a                 | 3.67±0.33a | 3.33±0.33c | 3.33±0.33c |
| MS              | 1.33±0.33a                  | 2.33±0.33a                 | 3.33±0.33a | 3.00±0.00c | 3.33±0.33c |
| BAP             | 2.00±0.58a                 | 2.33±0.33a                 | 4.33±0.33ab | 4.33±0.33c | 4.67±0.33c |
| BAS             | 1.67±0.33a                  | 2.33±0.33a                 | 4.33±0.33ab | 4.33±0.33c | 4.33±0.38c |
| BPS             | 1.67±0.67a                 | 2.33±0.33a                 | 4.33±0.33ab | 4.33±0.33c | 5.00±0.58c |
| PAPS            | 1.67±0.33a                 | 3.67±0.33a                 | 5.33±0.33d | 6.67±0.33d | 6.67±0.33d |
| Control         | 1.67±0.33a                 | 1.67±0.33a                 | 1.33±0.33a | 1.33±0.33a | 1.67±0.33a |

Table 2. The agglutination titer of tilapia offspring from maternal immunity produced by various types of vaccines at the ages of 10, 20, 30 and 40 days post-hatching (mean±SE). MA: *A. hydrophila* monovalent, MS: *S. agalactiae* monovalent, MP: *P. fluorescens* monovalent, BAS: *A. hydrophila* and *S. agalactiae* bivalent, BAP: *A. hydrophila* and *P. fluorescens* bivalent, BPS: *P. fluorescens* and *S. agalactiae* bivalent, and PAPS: *A. hydrophila*, *S. agalactiae*, and *P. fluorescens* polyvalent vaccines. Values with different superscripts a,b indicate that their corresponding means are significantly different (P<0.05) according to one-way ANOVA followed by Duncan’s test.

| Type of vaccine | Agglutination titer (log2) | Day post-hatching (day) |
|-----------------|-----------------------------|-------------------------|
|                 |                             | 10 | 20 | 30 | 40 |
| MA              | 4.00±0.58ac                 | 3.67±0.33bc              | 1.67±0.33a | 1.33±0.33a |
| MP              | 4.00±0.00ac                 | 3.67±0.33bc              | 1.67±0.33a | 1.33±0.33a |
| MS              | 3.67±0.33a                 | 3.33±0.33a               | 2.33±0.33a | 1.33±0.33a |
| BAP             | 4.67±0.33ab                 | 4.67±0.33ab              | 2.33±0.33a | 1.67±0.33a |
| BAS             | 5.00±0.58ac                 | 4.33±0.33bc              | 2.33±0.33a | 1.67±0.33a |
| BPS             | 4.33±0.33bc                 | 4.33±0.33bc              | 2.33±0.33a | 1.33±0.33a |
| PAPS            | 6.33±0.33d                  | 5.67±0.33d               | 3.00±0.33d | 1.67±0.33a |
| Control         | 1.67±0.33a                 | 1.67±0.33a               | 1.67±0.33a | 1.33±0.33a |

Response which was then transferred to the offspring. This process was carried out in order to produce offspring that possess both lysozyme and antibodies and a high survival rate post-challenge test using pathogenic bacteria. This was better than the other treatments that made use of the bivalent and monovalent vaccines. The results from the observation of the broodstock for 28 days showed that the total leukocyte (Figure 1), phagocytic (Figure 2), antibody titer (Table 1), and lysozyme activity (Figure 3), started to increase in week two post-vaccination. The broodstock vaccinated with PAPS showed a higher increase in the immune response compared to the others that were
Figure 3. The lysozyme activity in the tilapia broodstock after being vaccinated with the various types of vaccines (mean±SE).

MA: *A. hydrophila* monovalent, MS: *S. agalactiae* monovalent, MP: *P. fluorescens* monovalent, BAS: *A. hydrophila* and *S. agalactiae* bivalent, BAP: *A. hydrophila* and *P. fluorescens* bivalent, BPS: *P. fluorescens* and *S. agalactiae* bivalent, and PAPS: *A. hydrophila*, *S. agalactiae*, and *P. fluorescens* polyvalent vaccines. Values with different superscripts a,b indicate that their corresponding means are significantly different (P<0.05) according to one-way ANOVA followed by Duncan’s test.

Figure 4. The lysozyme activity of tilapia offspring from maternal immunity produced by various types of vaccines at the ages of 10, 20, 30 and 40 days post-hatching (mean±SE).

MA: *A. hydrophila* monovalent, MS: *S. agalactiae* monovalent, MP: *P. fluorescens* monovalent, BAS: *A. hydrophila* and *S. agalactiae* bivalent, BAP: *A. hydrophila* and *P. fluorescens* bivalent, BPS: *P. fluorescens* and *S. agalactiae* bivalent, and PAPS: *A. hydrophila*, *S. agalactiae*, and *P. fluorescens* polyvalent vaccines. Values with different superscripts a,b indicate that their corresponding means are significantly different (P<0.05) according to one-way ANOVA followed by Duncan’s test.

vaccinated with the bivalent, monovalent vaccines, and was the lowest in the unvaccinated broodstock. This showed that PAPS could increase the Nile tilapia broodstock’s immune response better than the other treatments.

The offspring produced from the broodstock that were vaccinated with PAPS had the highest antibodies (Table 2) and lysozyme activity (Figure 4) up to the 30th day post-hatching period and was the lowest in the offspring from the unvaccinated broodstock (P<0.05). This demonstrated that their strong immune response was transferred to their offspring through the egg yolk.

The results from the challenge test using pathogenic bacteria (Table 3) showed that the offspring that were produced using PAPS had a higher RPS compared to those from the offspring produced from broodstocks that were treated using the monovalent and bivalent vaccines (P<0.05). This further showed that the vaccine treatment had adequately protected the fish from bacterial diseases with an RPS that was...
greater than 60% up to the 30th day post-hatching period\[^9\].

RPS of the offspring vaccinated with formalin-inactivated vaccine in this study was higher at same time and lasted longer than the findings of Nurani et al.\[^4\] on days 10 and 20, closely similar to the Sukenda et al.\[^10\] and Pasaribu et al.\[^4\], but higher on day 20. The high RPS in the offspring during the challenge test using pathogenic bacteria in PAPS treatment was due to the broodstock’s high number of leukocytes, phagocytic activity, the amount of antibody, and lysozyme activity transferred to the offspring for protection against diseases. Meanwhile, in the control (unvaccinated), it only relies on immunity transferred naturally from the broodstock, whereas in the vaccinated broodstock, the offspring also get immunity from the broodstock which is induced by the vaccine. The existence of vaccine induction in the broodstocks can increase the total leukocytes, phagocytic activity, antibodies, and lysozyme activity of the offspring which are higher than the offspring produced from unvaccinated broodstocks. Thus, in the challenge test, the immune response of the vaccinated offspring is sufficient to control bacterial attacks, while the control offspring have not been able to control bacterial attacks. Compared to the Abu-elala et al.\[^3\] study, the offspring immune response RPS was higher and could last up to 3 months, whereas in this study, the PAPS RPS vaccine was lower and only lasted up to days 30. Indicating that the role of the maternal immunity-derived polyvalent vaccine can protect the offspring from disease attack up to 30 days of age thus after 40 days of age the seeds only rely on the immune response naturally transferred from the mother or begin to produce their own immune response. The low RPS of the PAPS vaccine therefore requires improvement in the application of the maternal immunity method, such as the use of adjuvants, the use of quality tilapia broodstock, proper nutrition in terms of quality and quantity, and the application of biosecurity in the hatchery\[^5\].

The role of leukocytes which consist of neutrophils, lymphocytes, and monocytes, is to infiltrate the infected area for rapid protection\[^6\], stimulating the production of antibodies through the recognition of foreign bodies, including vaccines and pathogens during the challenge test in this study. The phagocytic activity occurs during phagocytosis, which involves antibodies and complements during opsonization. Furthermore, the total leukocyte parameter increases in line with other immune responses, such as the antibacterial lysozyme, which triggers the complement system and phagocytic cells\[^6\]-\[^8\]. It encourages phagocytosis by activating leukocytes and polymorphonuclear macrophages or through opsonization\[^9\]. The high number of leukocytes and a large amount of lysozyme in the treatment using PAPS which is similar to an infection by a pathogen indicated the success of PAPS in triggering the fish’s immune system when developing an immune response.

The offsprings produced by the broodstock that were vaccinated with PAPS were protected from infections by *A. hydrophila*, *S. agalactiae*, and *P. fluorescens*. However, the monovalent vaccines only protected the offsprings from one type of bacteria. This is one of the advantages of applying PAPS. The results of this study revealed that the application of PAPS produced broodstock and offspring with better immune responses than the bivalent and monovalent vaccines. Therefore, the development of a polyvalent vaccine is more prudent than that of bivalent or monovalent because of its ability to target more than one species of bacteria\[^10\]-\[^13\]. The use of this type of vaccine caused the fish to respond to multiple antigens and form an immune response, thereby making it a strategic method in controlling bacterial diseases commonly found in culture and breeding environments\[^14\]-\[^16\]. Additionally, the application of polyvalent vaccines is more practical than the monovalent containing only one type of

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**Table 3. The Relative Percentage Survival (RPS) of tilapia offspring from maternal immunity produced by various types of vaccines at the ages of 10, 20, 30 and 40 days post-hatching.** The offspring were produced by broodstock vaccinated with various types of vaccines through intramuscular (i.m.) injection (mean±SE).

| Type of vaccine | Day post-hatching (day) |
|-----------------|-------------------------|
|                 | 10          | 20          | 30          | 40          |
| MA              | 66.67±4.81* | 55.26±5.26* | 41.03±2.56* | 14.29±4.96* |
| MP              | 61.11±2.78* | 50.00±6.96* | 41.03±2.56* | 14.29±4.96* |
| MS              | 63.89±2.78* | 52.63±4.56* | 43.59±2.56* | 17.14±2.86* |
| BAP             | 72.22±2.78* | 60.53±4.56* | 46.15±4.44* | 11.43±2.56* |
| BAS             | 69.44±2.78* | 60.53±4.56* | 46.15±4.44* | 14.29±4.95* |
| BPS             | 69.44±7.35* | 57.89±6.96* | 43.59±2.56* | 11.43±2.86* |
| PAPS            | 86.11±2.78* | 78.95±2.63* | 56.41±5.13* | 20.00±2.86* |

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\[^*\] Statistical significance, *P<0.05*.
antigen. This showed that PAPS provided the most effective protection against diseases caused by pathogenic bacteria that often affect fishes, and thus is an ideal candidate for developing a polyvalent vaccine against bacterial infection.

**Conclusion**

The results show that the application of the polyvalent vaccine against *A. hydrophila, S. agalactiae*, and *P. fluorescens* increased the antibody, lysozyme, total leukocytes, and phagocytic activity in Nile tilapia broodstock which was transferred to their offsprings, leading to a high RPS during the challenge test. Polyvalent vaccines derived from maternal immunity can protect offspring from disease up to 30 days of age. Therefore, it is possible to produce seeds of Nile tilapia that are immune to diseases caused by *A. hydrophila, S. agalactiae*, and *P. fluorescens*. This process could be carried out through the vaccination of the broodstocks using a polyvalent vaccine against *A. hydrophila, S. agalactiae*, and *P. fluorescens*.

**Ethical statement**

Research using fish in Indonesia has not been regulated and therefore it does not require animal ethics. However, this research has received approval from the Ministry of Education and Culture of the Republic of Indonesia (No.: 004/PL.22.7.1/SP-PG/2019). In addition, this study applies the principle of the International Animal Welfare standards including the assurance of fish welfare during maintenance and the use of drugs during sampling.

**Data availability**

**Underlying data**

OSF: Underlying data for “Transfer of maternal immunity using a polyvalent vaccine and offspring protection in Nile tilapia, *Oreochromis niloticus*”, https://doi.org/10.31219/osf.io/cnqd6

The project contains the following underlying data:

- Data on broodstock immune response, offspring immune response, and offspring RPS in tilapia, *O. niloticus* can be accessed on OSF

Data are available under the terms of the Creative Commons Zero “No rights reserved” data waiver (CC0 1.0 Public domain dedication).

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Special gratitude also goes to the Director of Pangkep State Polytechnique of Agriculture, South Sulawesi, Indonesia for allowing the sample analysed in the laboratory.

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Current Peer Review Status: ✔️ ✔️ ✔️

Version 4

Reviewer Report 27 November 2023
https://doi.org/10.5256/f1000research.156437.r222370

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Indriyani Nur
Department of Aquaculture, Faculty of Fisheries and Marine Science, Halu Oleo University, Kendari, South East Sulawesi, Indonesia

There will be no corrections from me to this manuscript any more. Everything has been revised by the authors. Therefore, it deserves to be approved.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Health of Aquaculture Organisms

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 3

Reviewer Report 08 September 2023
https://doi.org/10.5256/f1000research.144612.r193310

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Indriyani Nur
Department of Aquaculture, Faculty of Fisheries and Marine Science, Halu Oleo University, Kendari, South East Sulawesi, Indonesia

This study examines the presence of maternal immunity and the ability of polyvalent vaccines to
protect offspring for several days. Some notes and corrections to the manuscript, including:

1. Please, describe how to collect eggs after spawning and hatching the eggs?

2. Please, describe in more detail the agglutination test, such as: (1) the serum dilution in each well, (2) how about wells for positive and negative control?

3. Make sure the information/symbol in the legend is the same as what is written in the caption figure or table.

4. What are the unit for agglutination titer in Tables 1 and 2?

5. On the 40th day, the observed parameters in all treatments were not significant, what does that mean on offspring?

6. There are several sentences that need to be revised according to the comments on manuscript.

**Is the work clearly and accurately presented and does it cite the current literature?**
Yes

**Is the study design appropriate and is the work technically sound?**
Yes

**Are sufficient details of methods and analysis provided to allow replication by others?**
Yes

**If applicable, is the statistical analysis and its interpretation appropriate?**
Yes

**Are all the source data underlying the results available to ensure full reproducibility?**
Yes

**Are the conclusions drawn adequately supported by the results?**
Yes

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Health of Aquaculture Organisms

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.
P3: Intro

Streptococcus agalactia, Aeromonas hydrophila, Edwardsiella ictaluri, Flavobacterium columnaris, and Pseudomonas fluorescens are the pathogens. Disease refer to the infection, for examples Streptococcus agalactiae infection, Aeromonas hydrophila infection. Please revise. Consider 'Streptococcus agalactiae, Aeromonas hydrophila, Edwardsiella ictaluri, Flavobacterium columnaris, and Pseudomonas fluorescens infections'.

Tilapia lake virus is the pathogen, the disease is tilapia lake virus disease.

Para 2

'The offspring of fish' instead of 'their offspring' because 'they' refers to 'vaccines'

Para 4

It isn't applying polyvalent vaccines in offspring through maternal immunity, but 'application of polyvalent vaccines to confer maternal immunity in offspring'. Please rephrase.

Methods

Para 1, experimental animal

What size was the spawning ponds that you managed to replace 25% of water daily? Please provide the dimension (LxWxD).

Para 2, vaccine production

The test vaccine. Please provide reasons why S.agalactiae and P. fluorescens were inactivated with 1% formalin while A.hydrophila inactivated with 0.6%?
P4: Para 1, vaccine treatments and administration

Did you vaccinate both female and male broodstocks, or only female? Please mention. Revise 'However, before being injected with the vaccines, they were first anesthetized using MS-222, Sigma.' Consider: The fish were anesthetized using MS-222 (Sigma) prior to injection.

Para 2

25x30x1.2 m (L×W×D)

Para 3

Broodstock and larvae immune response. Intramuscular blood samples? Not caudal vein?

Para 4

Instead of 'post-spawning period', 'post-hatching period' will better reflect the offspring size. Please revise.

How many offspring was ground in a tube, and what kind of tube was it? Why was there a range of 5-10 minutes centrifugation time? If the samples were centrifuged for different lengths of time, would it have affected the parameters later? Please clarify. Inactivate the complements or components? What type of antigen? Whole-cell antigen?

Para 5: Challenge procedures

How long was the immersion in water containing pathogenic bacteria?

P4 Results

Broodstock total leukocyte dan phagocytic activity post vaccination PAPs did not result in highest total leukocyte in different time frames. BAP was highest on day 14.

P5, para 1: Broodstock and offspring agglutination titers

Please provide explanation as to why the unvaccinated fish (control) also show agglutination titer (although lower).

Para 4, RPS of offspring post-challenge

86.11% (10 days old), 78.95% (20 days old) and 56.41% (30 days old) Please provide explanation as to why the offspring of PAPS vaccinated broodstock encountered drops of RPS from 10 days old to 30 days old.

P5, Discussion, para 1
Was carried out in order to produce...

P7, Para 1

The statement 'in the control (unvaccinated), there was no transfer of immunity from the mother' is not generally true. If the unvaccinated broodstocks have acquired immunity from prior infections, the immunity will have been passed on to the offspring as maternal immunity. It is only true that the offspring of the unvaccinated broodstocks did not have the vaccine-induced maternal immunity.

The statement 'the offspring hasn't been able to produce their own immune response, so the total leukocyte, phagocytic activity, antibody, and low lysozyme activity' is not true. The offspring of the unvaccinated broodstocks did show immune response to the bacterial challenge but at the lower level compared with vaccinated group.

**Is the work clearly and accurately presented and does it cite the current literature?**
Yes

**Is the study design appropriate and is the work technically sound?**
Yes

**Are sufficient details of methods and analysis provided to allow replication by others?**
Yes

**If applicable, is the statistical analysis and its interpretation appropriate?**
Yes

**Are all the source data underlying the results available to ensure full reproducibility?**
Yes

**Are the conclusions drawn adequately supported by the results?**
Yes

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Aquatic animal health, microbiology

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.
Chanagun Chitmanat
Faculty of Fisheries Technology and Aquatic Resources, Maejo University, Chiang Mai, Thailand

The work is clearly and accurately presented. It is interesting research and I hope they can further study for farm application. However, the other serious bacteria pathogen is missing. Please add more review about Flavobacterium columnare. In addition, the viral pathogen doesn't be mentioned. It seems survival rates were quite low after bacterial challenge. Please discuss about low survival and how to improve it.

This work, of course, has academic merit. This study was well designed, the details of the methods are enough and they could be replicated, and the statistical analysis was appropriate. However, please discuss more about the negative control. No challenge test for control groups? All the source data underlying the results were available to ensure full reproducibility and the conclusions are drawn adequately and supported by the results. However, I just wonder about the TiLV problem? Do you plan to produce vaccines?

In addition to the previous comments, enclosed is the manuscript with some additional comments.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: fish immunology, fish diseases, aquaculture, aquaculture extension

I confirm that I have read this submission and believe that I have an appropriate level of
The study examined the transfer of vaccine-induced maternal immunity in Nile tilapia, *Oreochromis niloticus* against *Aeromonas hydrophila*, *Streptococcus agalactiae* and *Pseudomonas fluorescens*. The protective effects of monovalent, bivalent and polyvalent vaccines were compared. The relative percentage survival in immersion challenges, agglutination titers and lysozyme activities indicated that the polyvalent vaccine induced significantly better immune response compared with the bivalent, monovalent and unvaccinated groups.

Part of the introduction is rather brief. Suggestion for improvement as follows:

1. Provide more references on vaccination in tilapia. The following two contain some of the relevant information
   - https://doi.org/10.1002/aah.10099
   - https://doi.org/10.1016/j.fsi.2019.04.052

2. Until which stage of offspring is the immune system not ready for immune response? Juvenile? Please elaborate more.

3. What types of Ig are transferable through eggs? Please elaborate.

Part of the method description is rather brief and lacks references. Suggestion for improvements as follows:

1. Provide the reference for the two formalin concentrations used for inactivation of bacteria.

2. Mention the site of IM injection and provide the reference.

3. Mention the final bacterial concentration (cfu/mL) in the vaccines used at 0.4 mL/kg.

4. Mention the size of the dirt ponds.

5. Detail the antigen preparation for direct agglutination test. Was it monovalent, bivalent or polyvalent? Please see some additional annotations here.
References
1. Shirajum Monir M, Yusoff SM, Mohamad A, Ina-Salwany MY: Vaccination of Tilapia against Motile Aeromonas Septicemia: A Review. *J Aquat Anim Health*. 32 (2): 65-76 PubMed Abstract | Publisher Full Text
2. Laith AA, Abdullah MA, Nurhafizah WWI, Hussein HA, et al.: Efficacy of live attenuated vaccine derived from the Streptococcus agalactiae on the immune responses of Oreochromis niloticus. *Fish Shellfish Immunol*. 2019; 90: 235-243 PubMed Abstract | Publisher Full Text

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Aquatic animal health, microbiology

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Comments on this article

Version 3

Author Response 22 Sep 2023

Ardiansyah ardiansyah

Indriyani Nur, Halu Oleo University, Kendari, Indonesia
I highly appreciate the reviewer's comments and suggestions to improve the quality of the paper.
Our responses to comments and suggestions from reviewers can be seen in the table below:

Reviewer
1. Please, describe how to collect eggs after spawning and hatching the eggs

Author
Spawning and hatching of eggs were carried out naturally in ponds (cages), hence there is no post-spawning and hatching egg collection.

Reviewer
2. Please, describe in more detail the agglutination test, such as (1) the serum dilution in each well, (2) how about wells for positive and negative control?

Author
Methods, Broodstock and larvae immune response, Para-2

The direct agglutination test on both broodstocks and offspring was carried out by adding 25 µL PBS into the microplate from the 1st to 12th wells. A total of 25 µL of test fish serum based on treatment was added to the 1st well (positive control) and 2nd well. Furthermore, multilevel dilutions were carried out starting from the 2nd well to the 11th well, while the 12th well was not added with serum (negative control). Furthermore, 25 µL of whole cell antigen of bacteria A. hydrophila, S. agalactiae, and P. fluorescens were added to each of the 1st to 12th wells. The microtiter containing antibodies and antigens was then incubated overnight at room temperature and the agglutinating titer was calculated.

Reviewer
3. Make sure the information/symbol in the legend is the same as what is written in the caption figure or table.

Author
Thanks for the suggestion, we will modify it accordingly.

. Please refer to the results (Figure 1, 2, 3, 4)

Reviewer
4. What are the units for agglutination titer in Tables 1 and 2?

Author
Agglutination titer (log2). Please see the results (Table 1 and Table 2)

Reviewer
5. On the 40th day, the observed parameters in all treatments were not significant, what does that mean for offspring?

Author
6. In the Discussion section (Paragraph 4)
Indicating the role of the Polivalent vaccine derived from maternal immunity can protect the
offspring from disease attacks up to 30 days of age thus after the seeds are 40 days old the seeds only rely on the immune response transferred naturally from the mother or begin to produce their immune response.

Reviewer
7. There are several sentences that need to be revised according to the comments on the manuscript.
Is the work clearly and accurately presented and does it cite the current literature?

Author
Thank you for the suggestion, We will correct it accordingly

Reviewer
8. - Abstract, background
For this process to take place, the transfer of maternal immunity must be implemented.

Author
.........should be............

Reviewer
9. - Abstract, methods
Nile tilapia broodstock, with an average weight of 203g (±SD 23 g) was injected with a vaccine used as a treatment.

Author
Thanks for the suggestion, we will modify it accordingly.
.........203g (±SD 23).................

Reviewer
10. - Abstract, methods
The broodstock's immune response was observed on the 7th, 14th, 21st, and 28th day,

Author
Thank you for the suggestion, We will correct it accordingly (..days..)

Reviewer
11. - Methods, Experimental Animal, Para-1
They were kept in spawning ponds (25X30X1.2 LxWxD) and fed ad libitum with pellets that

Author
We will correct it accordingly (ad libitum)

Reviewer
12. Methods, Broodstock and larvae immune response, Para-2
Random blood sampling from the offspring was conducted on each treatment group
(Reviewer: Blood or serum?)
The blood was collected from offspring, In the next stage, the serum will be separated from the blood for the agglutination titer (antibody) test.

The offspring challenge test was conducted on the 10, 20, 30, and 40 days old during the post-hatching period.

Challenge tests were conducted with 3 types of bacteria simultaneously; A. hydrophila, S. agalactiae, and P. fluorescens.

This test was carried out by placing 20 offsprings in water containing pathogenic bacteria at a dose of $2.1 \times 10^8$ cfu/mL.

Challenge tests were conducted with 3 types of bacteria simultaneously; A. hydrophila, S. agalactiae, and P. fluorescens.

The results show that the application of the polyvalent vaccine against A. hydrophila, S. agalactiae, and P. fluorescens increased the antibody, lysozyme, total leukocytes, and phagocytic activity in Nile tilapia broodstock which was transferred to their offsprings, leading to a high RPS during the challenge test. hingga umur 30 hari. Therefore, it is possible to produce seeds of Nile tilapia that are immune to diseases caused by A. hydrophila, S. agalactiae, and P. fluorescens. This process could be carried out through the vaccination of the broodstocks using a polyvalent vaccine against A. hydrophila, S. agalactiae, and P. fluorescens. (Reviewer: Can provide protection to offspring for how long?)

Polyvalent vaccines derived from maternal immunity can protect offspring from disease up to 30 days of age. 

**Competing Interests:** No competing interests were disclosed.
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