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Survey on egg and fry production of giant gourami (*Osphronemus goramy*): Current rearing practices and recommendations for future research

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Abstract

Giant gourami (*Osphronemus goramy*) is one of the main freshwater fish of economic importance in Indonesia. Although this species has been reared for decades, particularly in the province of West Java, and naturally spawns in captivity, the availability of fry is still a limiting factor in aquaculture. Research efforts on giant gourami aquaculture are, however, limited and do not always address the difficulties encountered by fish farmers. The objectives of the present study were to provide the first description of giant gourami egg and fry production and highlight the main problems faced by farmers through targeted questionnaires and interviews. Our results show that the production of this species from eggs to juveniles is highly segmented, and there are currently no clear and standardized production methods. Farming practices vary greatly from one fish farmer to another. Climate factors (such as rain and temperature), proximity to urban areas, and the availability and quality of food are identified as the main limiting factors for egg and fry production. Based on a strengths, weaknesses, opportunities, threats analysis, we explore possible approaches to improve giant gourami aquaculture in Indonesia. The present study provides guidance for future research.

KEYWORDS
Giant gourami, Indonesia, larval rearing, small-scale aquaculture, SWOT analysis

1 | INTRODUCTION

With a production of 3 million tons of farmed fish in 2015, Indonesia is the third largest freshwater fish aquaculture producer country after China and India (FAO, 2017). Aquaculture production has shown the most rapid expansion among all Indonesian agronomic production sectors, with an average annual growth of 7% (FAO, 2017) after the government made aquaculture development a national priority in 2009 (Philips et al., 2015; Rimmer, Sugama, Rakhmawati, Rofiq, & Habgood, 2013). Freshwater fish farming, which represents 67% of aquaculture production in Indonesia (FAO, 2017), uses traditional production systems mainly based on traditional practices (Edwards, Little, & Yakupitiyage, 1997). This sector plays a significant role in the Indonesian economy, ensuring food availability and household food security and improving living standards for rural communities (Rimmer et al., 2013). In Indonesia, 3.34 million fish farmers practice aquaculture (FAO, 2018) but with a low national productivity (i.e., 1.48 t/farmer) compared with other Asian countries (1.72 t/farmer in Asian countries excluding Indonesia and China; FAO, 2018). This low production output is especially true for freshwater fish aquaculture, which is mainly carried out in small-scale farms, often associated in small groups called “kelompok,” which represent more than 90% of all fish farms (Maskur, Rina, & Hamid, 2013).

Among the freshwater fish produced in Indonesia, the giant gourami (*Osphronemus goramy* Lacepède, 1801) is one of the main local species of economic importance. Its annual production was over 119,000 t in 2014 and had grown exponentially over the previous 15 years (FAO, 2017). This fish has become one of the main species being farmed and is in great demand in the food aquaculture industry (Amornsakun, Kullai, & Hassan, 2014a). Giant gourami is particularly promising in view of its air-breathing capacities and its diet with a strong vegetarian component (Slembrouck et al., 2018), thereby lowering feeding costs. Furthermore, international institutions are promoting the production of local species in aquaculture (FAO, 2016; Ross, Martinez Palacios, & Morales, 2008; Saint-Paul, 2017), a trend that is backed by the Indonesian government, which adopted the concept of “blue growth” for aquaculture in 2014 (Tran et al., 2017).

Although the giant gourami is an interesting species in view of current Indonesian aquaculture guidance, its production has slowed for various reasons. Because of its traditional production practices based on empirical know-how, there are still gaps in knowledge on several aspects of the biology of this species, particularly for the juvenile life stages (Arifin, Prakoso, Kristanto, Pouil, & Slembrouck, 2019). One of the main impediments in giant gourami aquaculture is ensuring a regular supply of fry (Slembrouck et al., 2019). Giant gourami is a species able to reproduce spontaneously in captivity. Currently, fry typically come from natural spawning events and are reared in outdoor ponds in stagnant water conditions. Their availability for farmers is generally low and highly variable (Arifin, At-thar, & Nafiqoh, 2013; Budi & Suprayudi, 2015; Etoh, Putra, & Carman, 2011; Nafiqoh & Nugroho, 2013) and should be improved through more reliable production methods (Amornsakun et al., 2014a; Amornsakun, Kullai, & Hassan, 2014b). Nevertheless, the improvement of rearing techniques requires significant research efforts that are not currently undertaken (Prakoso et al., 2019). In addition, to be effective, research efforts should focus on the difficulties faced by fish farmers, and these should be clearly identified before undertaking scientific investigations.

For the above-mentioned reasons, giant gourami aquaculture is currently very poorly characterized. This study was therefore conducted (a) to describe the status of giant gourami fry production practices in the province of West Java through questionnaires administered to local fish farmers and an assessment of the strengths, weaknesses, opportunities, and threats (SWOT analysis) and (b) to provide some recommendations to guide future research on this species.

2 | MATERIALS AND METHODS

2.1 | Selected study areas

Giant gourami production is mainly located on Java Island (79% of the national giant gourami production; BPS, 2013). The production cycle of this species, presented in a simplified view in Figure 1, is highly segmented, and there are many market stages (Sarah, Widanarni, & Sudrajat, 2009). This segmentation can reasonably be attributed to the slow growth of this fish and the difficulties encountered in the production chain (FAO, 2019). In this study, we focused on the most critical production stages: from broodfish management to the production of fry called "nguku" (*length*: 1.5–2.5 cm; name used by farmers and corresponding approximately to the width of a thumbnail; Adida, 2014). On this basis, our analysis focused on West Java. A west–east gradient was considered, with major production areas near Bogor in the west and Tasikmalaya in the east, so as to best capture the different rearing practices of gourami fry (Figure 2). An extensive field-based "rapid reconnaissance" (Hernandez et al., 2018) was then carried out to identify the major clusters of giant gourami aquaculture in the selected areas with the help of the Local Animal

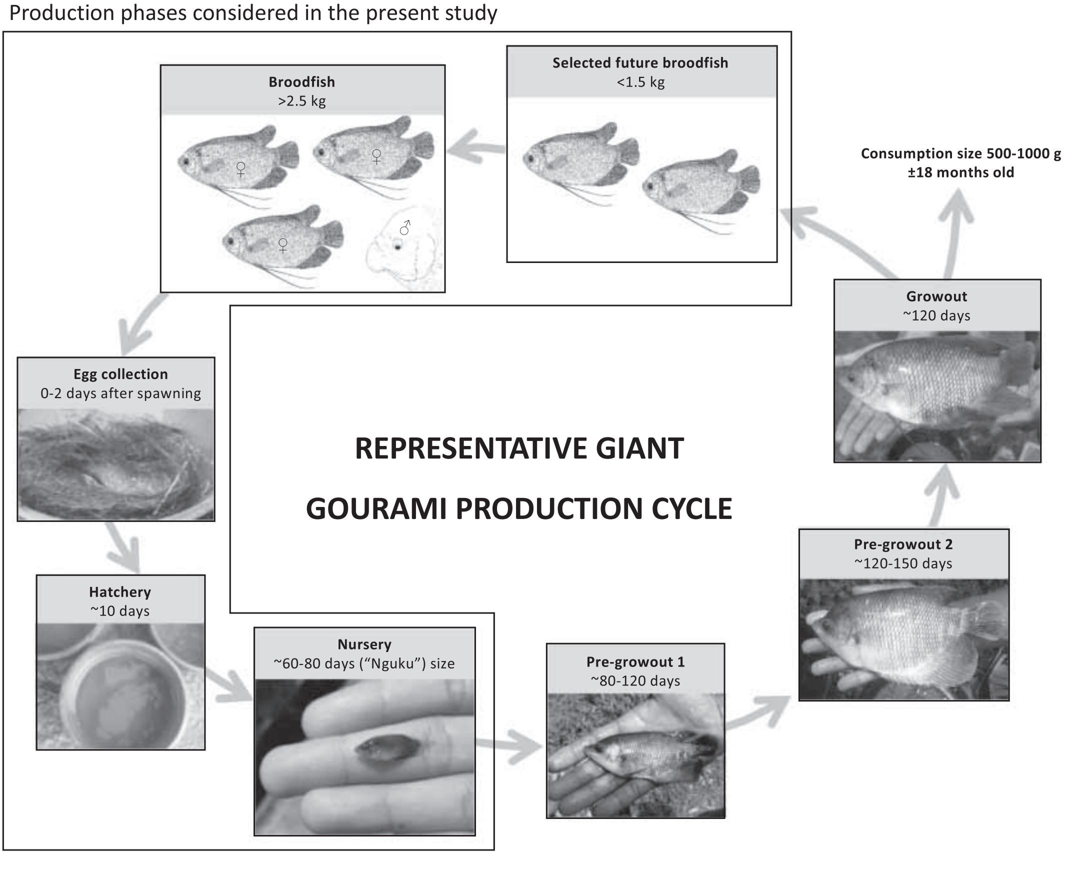

FIGURE 1 Representative production cycle of giant gourami *Osphronemus goramy* in West Java (Indonesia; modified from FAO, in press). The present study focuses on the phases from broodfish management up to nursery fry production (the "nguku" stage)

Husbandry and Fisheries Service in the Bogor area and through the West Java Center for the Development of Giant Gourami Culture (BPPSIGN) in the Tasikmalaya area. The sample for the survey was drawn using purposive stratified random sampling because fish farming is concentrated in certain districts, and a nationally representative sample was not financially feasible (Hernandez et al., 2018).

2.2 | Establishment of questionnaires and interview process

A detailed questionnaire targeting fish farmers involved in gourami egg and fry production was prepared to evaluate the variability of spawning methods and efficiency, hatching success, and larval performance during the nursery

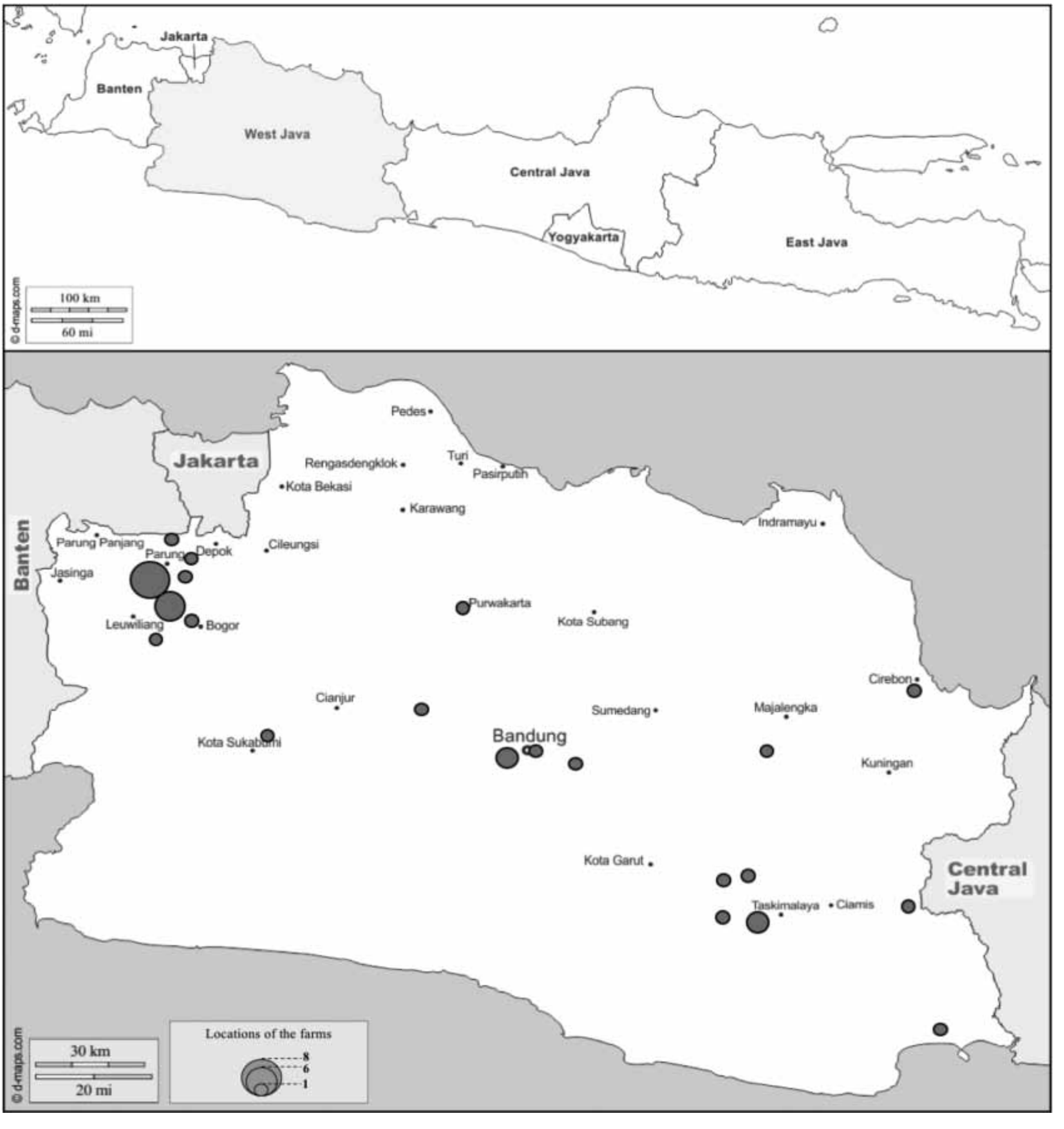

FIGURE 2 Locations of the giant gourami farms considered in this study (i.e., 35 independent farmers, four farmers members of a "kelompok," and two training centers) in the West Java province

production of giant gourami and to identify associated limitation factors. Survey questionnaires were divided into 14 categories of questions:

A–B. Farm location and description: Information about the location, the size of the production farm, and the type and size of the rearing structures.

C. Farmer presentation: Experience of the fish farmer, age, and education level.

D–E. Farmed fish description (giant gourami and other species): List of the species reared (in addition to giant gourami), giant gourami strains reared.

F–G. Broodfish maintenance and spawning conditions: Number of broodfish, sex ratio, water renewal, feeding strategy, pond fertilization, type and size of the rearing and spawning structures, problems faced.

H–I. Egg production results: Number of spawning events per month, number of eggs collected, incubation conditions, quality and viability of the eggs (estimated from the proportion of white-dead eggs generally observed in spawns).

J. Larval rearing up to the "nguku" stage: Larval rearing structure description, duration, water renewal, temperature, first food intake, feeding strategy, survival rates, problems faced.

K–L. Perception of limitations for fry production: Farmer's opinion about the main problems limiting spawning and larval rearing of giant gourami.

M. Information needs of fish farmers: Gaps in knowledge identified by the farmer.

N. Economy and market: Information regarding selling prices and marketing of fry: market location and type of customers.

The questionnaire, originally written in English and translated into Indonesian, included 142 questions (multiple-choice questions, textual and numerical questions), both on qualitative and quantitative aspects of the production. The 2-hr questionnaire was completed through an individual interview carried out at each production site, except for nine farmers who completed the questionnaire during a technical internship at the Tasikmalaya training center. Two people were present during the interviews to introduce the objectives and ensure that each question was understood. When necessary, the questions were translated into the native language (Sundanese). In addition to the questionnaire, field measurements of water quality (temperature, pH, dissolved oxygen, conductivity, turbidity) were taken in the rearing structures. Participation in this study was entirely voluntary. A total of 35 independent farmers, four farmers organized as "kelompok," and farmers at two training centers were interviewed between May and November 2016.

2.3 | Data analysis

Initial data processing was performed to identify ambiguous responses or deviations from observed trends, and some farmers were contacted again in March 2017 for clarification and/or confirmation.

Quantitative data (i.e., area of farms, area of rearing structures, number of employees, number of spawners) were plotted to provide the first visual examination of possible relationships between variables. Based on this first examination, linear regressions were then used to test, among other things, the relationship between farm size and number of employees and egg production by number of brooders per farm.

As assumptions of normality and homogeneity of variances were unable to be achieved, the size of the farms was compared according to their level of proximity to urban areas ("low," "medium," and "high") using a nonparametric Kruskal–Wallis test followed by a Siegel and Castellan test (Siegel & Castellan Jr., 1988). The size of the farms was also compared between the two production strategies observed (i.e., farms dedicated to gourami production and multispecies farms) using a nonparametric Mann–Whitney *U* test.

A Chi-square test (χ^2) was used to define statistical differences in the farmers' responses for the most sensitive larval production stages.

The level of significance for statistical analyses was set at α = .05. All statistical analyses were performed using R freeware version 3.3 (R Development Core Team, 2016).

3 | RESULTS AND DISCUSSION

3.1 | Production chain of giant gourami fry

Despite a production rate of more than 100,000 t per year, there is very little information available in the scientific literature regarding the rearing techniques of the giant gourami. The objective of the following section was therefore to provide new insight into the production chain of giant gourami fry based on answers from the surveyed Indonesian farmers. The answers provided by training centers were sometimes used for comparison. In most cases, percentage data are associated with the number of respondents, are question-dependent, and are indicated in parentheses. Unless otherwise stated, values are means ± *SD*. Studied locations of production farms are indicated in Figure 2.

3.1.1 | Fish farmers and production site description

The interviewed fish farmers were 24–80 years old (47 ± 14 years, $n = 38$) and skilled in giant gourami aquaculture (14 ± 11 years of experience, median: 10 years, $n = 39$). Most farmers (87%) started giant gourami aquaculture as a vocational retraining. The family and/or training centers are the main ways for learning this occupation for most respondents (84%, $n = 25$). The education level was variable, with 31% of fish farmers having attended primary school (called Sekolah Dasar, SD), 25% junior high school (Sekolah Menengah Pertama, SMP), and 39% high school (Sekolah Menengah Atas, SMA), whereas only 5% ($n = 2$) had postsecondary degrees.

Overall, farm altitudes ranged from 110 to 540 m above sea level with lower elevations for farms in the northern part of Bogor. On Java Island, aquaculture is often conducted in periurban areas (Pribadi & Pauleit, 2016). Thus, 20% ($n = 6$) of farms were located in the middle of dwellings or in direct contact with a few dwellings, whereas 47% ($n = 14$) of the farms surveyed were in an area with limited urban development (>100 m from production ponds), and 33% ($n = 10$) are in an intermediate situation, with houses nearby but in a relatively open environment (e.g., houses close to one side of the farm and countryside on the other side). Farm size (3,811 ± 2,963 m^2, median: 2,679 m^2, $n = 38$) is significantly lower (Kruskal–Wallis test, $p < .01$) in urban or developed areas, and most of the largest farms were located in open areas (Table 1).

This survey demonstrated that giant gourami fry were not mainly produced by farmers focusing on this species: 32% of the respondents ($n = 12$) produce only giant gourami, and a large majority of farms (68%, $n = 26$) also produce other species in variable proportions (Figure 3). This is a typical characteristic of Javanese small-scale freshwater fish farming where farmers can quickly shift from one species to another to better adapt to the market and the difficulties encountered, conferring a greater resilience for this type of production system. In the interviewed farms, the most important species reared for human consumption were nonnative species (Figure 3). These results reflect the national production statistics very well (i.e., 1.1 Mt of tilapias, 0.72 Mt of African catfish, and 0.46 Mt of common carp; FAO, 2017), also indicating that giant gourami is the major local fish species produced (FAO, 2017).

Interestingly, farms specifically dedicated to the production of giant gourami were significantly smaller (Mann–Whitney *U* test, $p < .01$) than multispecies farms. These quantitative observations support the fact that giant gourami aquaculture was mainly practiced in small-scale fish farms. The rearing structures larger than 100 m^2 were mostly earthen ponds. However, for smaller structures, 54% of the respondents ($n = 21$) reported having between 8 and 100% of their earthen ponds constructed with concrete banks. The number of production ponds per farm varied from 3 to 85 (16 ± 15 ponds, median: 12 ponds, $n = 39$). The water supply to the ponds was mainly provided by surface water (55% of the respondents, $n = 21$), while drilling water was the water source for the ponds in 24% of the farms ($n = 9$). Interestingly, all the farms located in the most developed areas ($n = 6$) receive only surface water, potentially increasing the risk of exposure to anthropogenic contaminants and, therefore, the risk of disease and mortality for fish through the deterioration of the water quality, although this relationship was not statistically demonstrated.

TABLE 1 Main characteristics of the giant gourami production sites in West Java province

Characteristics	Fish farms (*n* = 35–39)	Training centers (*n* = 2)
Proximity to developed areas (% of the production sites)	*High*: 20% *Medium*: 33% *Low*: 47%	*Low*: 100%
Altitude (*m*)	110–540	88–480
Surface of the farm (m^2)	3,811 ± 2,963	25,000–29,000
Type of ponds	Concrete pond Earthen pond Earthen pond with concrete banks	Earthen pond Earthen pond with concrete banks
Number of ponds	16 ± 15	79–106
Giant gourami rearing only (% of the production sites)	32%	100
Origin of the water used	*Surface water*: 55% *Drilling water*: 24% *Mixed water*: 21%	*Surface water*: 100%

Note: Kelompok (fish farmer groups) were excluded for the surface of the farms and the number of ponds.

Overall, there were an average of two employees per farm in addition to the farmer (2.0 ± 1.2, *n* = 37). The number of employees was not significantly related to farm size, although the absence of employees was observed only in the smallest farms.

3.1.2 | Broodstock management and selection

It can be difficult to characterize the different strains of giant gourami reared in Indonesia because their vernacular names vary according to localities. Currently, more research is being conducted to improve strain characterization (Azrita & Syandri, 2015; Nuryanto, Amalia, Khairani, Pramono, & Bhagawati, 2018). Interviewed farmers (*n* = 38) reported that they own between one and four different strains of broodfish. The strains used vary according to farm location. In Tasikmalaya, the "Galunggung" strain (Arifin et al., 2017) is clearly dominant (presence in all farms monitored). In the Bogor district, the situation is more complex. Although there is a dominant strain called "Bastar" (Nuryanto et al., 2018) used by 68% of farmers (*n* = 15), other strains coexist and are used in variable proportions.

In most cases, broodfish or future broodfish are purchased from other fish farmers, usually in the vicinity (86%, *n* = 32). Nevertheless, 46% of the interviewed farmers reported that they produced, at least partially, their own future broodfish. The number of broodfish kept on farms ranged from 12 to 200 (70 ± 48 broodfish, median = 50 broodfish, *n* = 36) without any significant relationship with the total surface of the farm. Characteristics of the broodfish used are summarized in Table 2.

The stocking density in spawning structures varied between 0.02 and 0.75 fish/m^2, with an average of 0.17 ± 0.15 fish/m^2 (median: 0.13 fish/m^2, *n* = 30). In training centers, values were 0.15–0.20 fish/m^2. The standard values were one fish for 5–6 m^2 maintained in one to four ponds in open-flow or regularly changed water conditions, although there were a few exceptions. Water quality measurements taken in broodstock ponds suggested that, for the various measured parameters, values are generally within the recommended range (SNI, 2006) except for temperature. Indeed, we found that temperature exceeded the recommended value of 30.0°C during the day in 75% of the measurements recorded (Table 3).

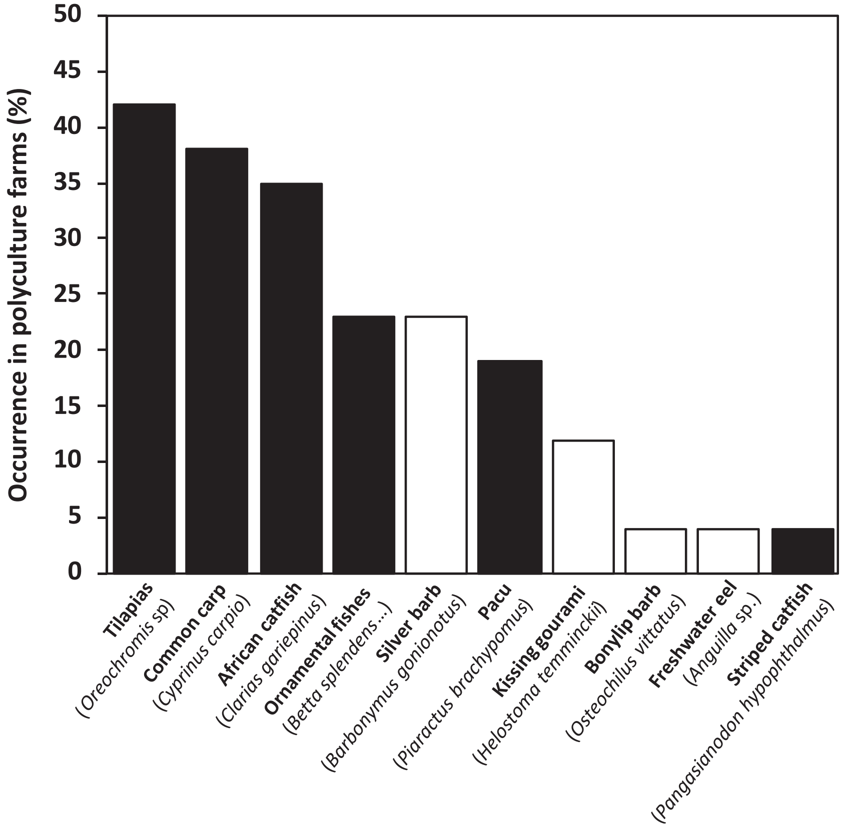

FIGURE 3 Occurrence (%) of the fish species (other than giant gourami) reared in the studied multispecies farms. Local species reared for human consumption are indicated in white and nonnative species in black

The average pond size used for reproduction varied from 24 to 1,100 m^2 (*median*: 300 m^2, n = 33). There were two strategies for egg production: (a) the broodfish were maintained together in a communal open pond (78%, n = 32) or (b) the broodfish were maintained in compartmentalized ponds (10%, n = 4) where there was only one male per compartment with a variable number of females (strategy mainly used in Central Java Province). According to the fish farmers, the main advantages of using compartments were to avoid aggression between males and to facilitate broodstock management.

Although 100% (n = 11) of fish farmers using ponds with concrete banks provided broodfish with supports for nest building, this was not always the case when earthen ponds were used for egg production. For instance, 11 of 26 farmers (42%) did not provided nest supports; in these cases, the fish build their nests in bank crevices, most often dug by fish farmers. Other fish farmers (58%) provided nest supports most often made of braided bamboo strips. Interestingly, the number of spawning supports did not correlate with the number of broodfish used. Although nest supports were not used systematically, all fish farmers provided various materials for the construction of nests, mainly palm tree fibers (97%), used alone or in combination with plastic fibers (75%), dry grass (25%), or coconut fibers (20%).

Farmers usually drain spawning ponds, on average, every 7 ± 8 months (median: 6 months, range: 1–36 months, n = 27) to clean the pond and/or change the broodfish. In most cases, the fish are kept in egg production structures throughout the year. Nevertheless, some farmers (9%, n = 3), trained by BPPSIGN, reported that they separated males and females for 1 month for a resting period and fed them with pellets enriched with fermented soybean, poultry egg yolk, or vitamin E to replenish their energy reserves before starting a new 3-month egg production period.

TABLE 2 Management of giant gourami broodfish in the interviewed farms (*n* = 30–39)

Origin of the broodfish (% of the farms)	Number of broodfish per farm	Stocking density (fish/m^2)	Type of spawning structure (% of the farms)	Spawning pond size (m^2)	Minimal weight of broodfish (kg)	Minimal age of broodfish (years)	Age of broodfish at replacement (years)
Purchased (100%)	70 ± 48	0.17 ± 0.15	Communal pond (91%)	24–1,100	1.9 ± 0.5	3.6 ± 1.9	10.2 ± 4.5
On-farm production (46%)			Compartmentalized pond (11%)				

Note: The total proportions for the type of spawning structure are slightly higher than 100% because farmers can use both communal and compartmentalized ponds in the same farm.

TABLE 3 Summary of water quality parameters measured in the broodstock ponds (*n* = 39) and juvenile rearing structures (*n* = 47) between 8:15 a.m. and 6:30 p.m. during fish farmer surveys

Parameters	Observed ranges	Recommended ranges	Comments
Broodstock ponds (*n* = 39)			
Temperature (°C)	24.6–34.7	25.0–30.0 (SNI, 2006)	49% measurements >30.0°C
			26% measurements >32.0°C
Dissolved oxygen (mg/L)	0.4–16.3	>2.0 (SNI, 2006)	10% measurements <2.0 mg/L
pH	5.8–9.5	6.5–8.5 (SNI, 2006)	10% measurements <6.5
			1 extreme value at 9.5
Conductivity (μS/cm)	37–289	—	—
Turbidity (NTU)	3–134	>50 (Seim, Boyd, & Diana, 1997)	43% measurements >50 NTU
Fry rearing structures (*n* = 47)			
Temperature (°C)	27.1–39.9	29–30 (SNI, 2000a)	60% measurements >30.0°C
			30% measurements >32.0°C
Dissolved oxygen (mg/L)	3.4–12.5	>5 (Boyd & Tucker, 1998)	30% measurements <5 mg/L
pH	7.2–9.8	6.5–8.0 (SNI, 2000a)	47% measurements >8
Conductivity (μS/cm)	24–1,242	—	1 extreme value at 1,242 μS/cm
Turbidity (NTU)	1–282	>50 (Seim et al., 1997)	28% measurements >50 NTU

Note: Potential risks related to low dissolved oxygen are age-dependent because the labyrinth organ begins to develop in fry aged 30 dph, and air-breathing behavior is first observed after 35–40 dph (Morioka, Vongvichith, Phommachan, & Chantasone, 2013). One interviewed fish farmer adds lime and salt during larval rearing in undetermined quantity, which explains the extreme values observed for conductivity and pH.

The male-to-female (M:F) ratio of broodfish was independent of the strains and ranged from 1:2 to 1:9 (Figure 4). Nevertheless, 61% of the farmers use sex ratios of 1:3 and 1:4 (i.e., values close to the recommendations of the interviewed training centers and the Indonesian National Standards; SNI, 2000a, 2000b). Farmers generally use more females than males to minimize spawning disturbances because of the aggression of males and to optimize the utilization of the production surface. Based on BPPSIGN, selling prices for mature broodfish (~2 kg) were USD 4.6 kg^{-1} (i.e., ~USD 9.2 per individual, based on an exchange rate of USD 1 = IDR 14,102) and USD 6.9 kg^{-1} (i.e., ~USD 13.8 per individual) for males and females, respectively, whereas immature future broodfish (~700 g) were sold at USD 3.5–4.6 kg^{-1} (i.e., ~USD 2.5–3.2 per individual). Thus, for economic reasons, broodfish were often purchased young and immature. In these conditions, gender identification uncertainties were possible (see below) and thus explained the most uneven sex ratios, which were often unwanted. For example, one farmer (excluded in Figure 4) reported a sex ratio of three males to one female resulting from gender identification errors of immature broodfish.

According to fish farmers, the minimal size and age for using fish for reproduction were 1.9 ± 0.5 kg (median: 2.0, range: 1.0–3.0 kg, *n* = 34) and 3.6 ± 1.9 years (median: 3.0 years, range: 1.5–10 years, *n* = 34), respectively. Average values were close to the recommendations issued by the BPPSIGN training center. Farmers exchanged their broodfish when they reached an average age of about 10 years, but some of them kept their broodfish until they died (three farmers indicated that they owned broodfish of 20 years or older). The sexing of mature and future broodfish was a challenge in giant gourami aquaculture. In the absence of dedicated tools, sexing and assessment of sexual maturity were mainly based on external observations. To provide guidance for farmers, the Indonesian National Standard (SNI, 2000b) listed several morphological criteria that could be used for sexing males and females. According to SNI (2000b), mature males have a marked hump on the upper part of the head and a thickening of the lower jaw. Females can be identified by black pigmentation at the base of their pectoral fins. In addition to these criteria, fish farmers used other morphological and behavioral criteria to try to improve sexing success in giant gourami. Among them, body shape, caudal fin shape, and specific behavior during handling could be objectively determined. The most subjective criteria were not described here. In a recent study, Slembrouck et al. (2019) demonstrated that observations of the hump on the forehead, thickening of the lower jaw, and the pigmentation on the pectoral fin (not for light color phenotypes) were highly reliable for sexing (about 95% success). Nevertheless, to

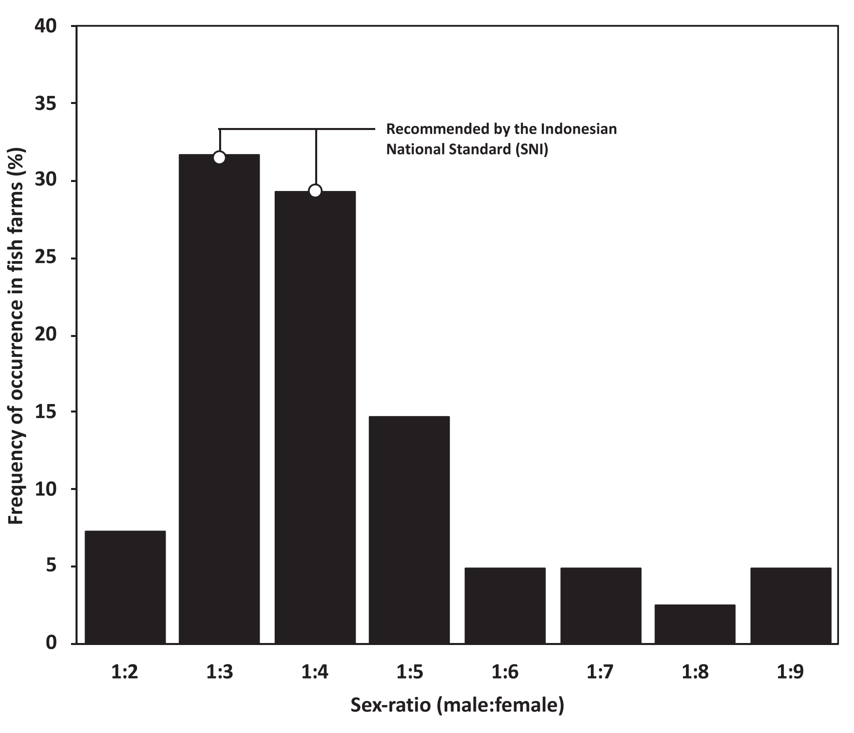

FIGURE 4 Sex ratios (male:female) used by interviewed farmers for giant gourami egg production

be efficient, observations of the selected criteria should be carried out using objective scales. The use of the intraovarian cannulation technique was the most accurate gender identification method but required specific cannulas and skills that make it unfeasible for most small-scale farms (Slembrouck et al., 2019). Authors also recommended confirming the gender of selected future brooders after they reached sexual maturity. This study also demonstrated that the criteria often used by fish farmers do not improve gender identification success.

Broodfish feeding consisted mainly of giant taro leaves (*Alocasia macrorrhizos*, 92% of the farmers, *n* = 34 and the training centers). In some cases (16%, *n* = 6), it was the only food used. Commercial pellets (floating pellets in 80% of the cases, 30 ± 4% of proteins) were used by 43% of the fish farmers (*n* = 16). Feeding strategies varied greatly among farmers using pellets: 69% feed the broodfish every day (*n* = 11, daily ration of 1% of the biomass), 19% every 2 days (*n* = 3), and 12% only once a week or less (*n* = 2). Interestingly, commercial pellets were always combined with plant food (mainly giant taro leaves). Only one farmer declared using homemade feed (molasses, yeast, fermented cassava, soy waste, rice bran, fishmeal). Some other food types (such as snails and several plant species, see Table 4) were used when the main feeds were not available or because they were perceived as useful supplements in improving the quality of the eggs.

Broodfish mortality occurred frequently for 58% of the interviewed farmers (*n* = 21), and disease was mentioned in 64% of the interviews (*n* = 25). The main disease agents identified by the fish farmers were ectoparasites such as *Lernaea* sp. (*n* = 9), fungi (*n* = 4), *Argulus* sp. (*n* = 2), and bacteria such as *Aeromonas* sp. (*n* = 2). In addition to disease, 58% of the farmers (*n* = 21) also observed other causes of broodfish mortality, such as aggressiveness (especially for males, *n* = 19), water quality (*n* = 6), handling (*n* = 5), and animal predation (*n* = 6). In addition, surrounding noise (spontaneously mentioned by 25% of farmers, such as motorbikes, firecrackers, etc.) was considered an important factor of stress likely to cause broodfish mortalities.

3.1.3 | Natural spawning

The giant gourami reproduces spontaneously in the spawning ponds. Once a pair is formed, a nest made of vegetable material is constructed, mainly by the male. Soon after oviposition and egg fertilization, the male closes the nest and

TABLE 4 Feeds and feeding strategy for giant gourami broodfish in the production site (*n* = 41)

Types of feeds	Occurrence in the broodfish diet (% of farms)	Comment
Main feeds		
Giant taro leaves (*Alocasia macrorrhizos*)	92	Main feed for giant gourami broodfish, 16% of the farmers used only this feed
Compounded pellets	41	*Mainly floating pellets (80%), protein*: 30 ± 4%, usually ≤1% of the biomass/day
Other feeds		
Taro leaves (*Colocasia esculenta*)	16	Alternative to giant taro leaves
Snail flesh	11	—
Papaya leaves	5	—
Cassava leaves	5	—
Other macrophytes	22	Including terrestrial and aquatic macrophytes (leaves, seeds, all plants), sometimes used as medicinal plants

guards the progeny. Almost 100% of the interviewed farmers checked the nest every day (median: 1 day, range: 0.5–7 days) in the ponds. The interviewed training centers checked nests daily or every 2 days. Nest closure and the presence of eggs and an oily film on the surface were the main indicators for identifying the presence of a spawn. Most of the interviewed farmers (91%, *n* = 29) observed seasonality in reproductive intensity.

In Bogor and its vicinity, the dry season (from March to September) was considered the best season for egg production, and August appears to be the best month for spawning for 68% of the interviewed farmers (*n* = 15). In Tasikmalaya, where the dry season was less marked (Climate Data, 2019), there was no clear seasonality reported in egg production. In the absence of sufficiently reliable data (particularly in egg counts), it was difficult to estimate seasonal changes in fish fecundity. On average, fish farmers estimate that, under their aquaculture conditions, a female spawns about every 3 months (from 1.6 to 12 months), whereas the minimum time interval between two successive spawns of the same female is 0.8 ± 0.9 month (median: 0.8 months or 24 days, *n* = 32). Our experimental data, obtained in another study on hundreds of spawns collected in controlled conditions, corroborate farmer affirmations, with the highest observed mean spawning frequencies of 0.2–0.5 spawns per female per month (depending on experimental situations), and the minimum time interval seen between two successive spawns of the same female is 20 days (authors, unpublished data). For the majority of the farmers interviewed (55%, *n* = 21), egg production remained stable over recent years, and only 11% (*n* = 4) mentioned decreases mainly attributed to pond instability or broodfish mortality. These results, limited to a small number of fish farmers, indicate that, in the province studied, the production of gourami eggs does not appear to have degraded.

3.1.4 | Egg production: From the nest to vitelline resorption

Egg management after egg laying varies among interviewed farmers. Nevertheless, the majority (87%, *n* = 33) collected the nests within 24 hours after spawning and incubated eggs in dedicated structures. However, 13% of fish farmers declared that they harvest the larvae hatched in the ponds. Most of the time, the farmers estimated the number of eggs per nest (92%, *n* = 35), and this number ranged from 1,500 to 8,500 eggs (4,369 ± 1,670, median: 4,500; Table 5). Based on an average weight of 3 kg for females, the relative fecundity can be roughly estimated at 1,500 eggs/kg (Table 5), a figure in accordance with data provided by the SNI (2000a, 2000b). Results concerning the viability of the eggs were very variable: 76% (*n* = 28) of the interviewed farmers indicated a viability of 80–90%, and 19% of the farmers provided viability rates of 50–90% in accordance with the two training centers (viability rates of 80–90%). Nevertheless, 72% of the interviewed farmers (*n* = 28) indicated that they collected, at least once, a completely unviable spawn (all eggs opaque and whitish). The main reasons given to explain the variability in egg viability were mainly related to the season, water quality, broodfish feeding, and fungus development on eggs. Most farmers (90%, *n* = 35) eliminated dead eggs before or at the beginning of incubation. Interestingly, 42% of the interviewed farmers sell at least a part of their own egg production to other giant gourami farmers (selling prices USD 3.3 ± 0.6 for 1,000 eggs based on an exchange rate of USD 1 = IDR 14,102).

TABLE 5 Summary of the egg production results in giant gourami production (*n* = 31–38)

Incubation practice (% of the farms)	Egg count estimation (% of the farms)	Number of eggs in a spawn	Estimated relative fecundity (egg/kg)	Number of spawning events/ female/month (in high season)	Egg viability (%)
In dedicated structures: 87%	*Yes*: 92%	4,369 ± 1,670	~1,500	0.30 ± 0.23	50–90
In broodfish ponds: 13%	*No*: 8%				

The vast majority of fish farmers (n = 32, 91%) incubated eggs in stagnant water contained in 20–50-L black plastic basins. The control of environmental conditions is very limited during the incubation step. Nevertheless, incubation usually took place in a covered place to protect eggs and larvae from rain. For the majority of fish farmers, it is temperature that mainly affects the results of this rearing phase. Based on farmers' declarations, the incubation time of gourami eggs varied between 2 and 4 days (median = 2.8 days, average ± *SD*: 2.7 ± 0.7 days, n = 30). Posthatch larvae were retained in the incubation structure (usually black basins) for 6–15 days (median = 9.5, average ± *SD*: 9.4 ± 2.4 days, n = 34) before being transferred to larval-rearing structures. Usually, during this period, larvae were not fed, and water was not renewed. In 100% of the cases, larvae were transferred to the larval-rearing structures when they were able to swim actively (the "berenang" stage) and sometimes after complete yolk sac resorption (i.e., after 14–15 days posthatching at 25–30°C; Morioka et al., 2013).

3.1.5 | Larval rearing: From larvae to "nguku" fry

The time for the first feeding of larvae was highly variable, between 3.5 and 21 days postharvest (dph), according to the farmers (10.5 ± 4.5 dph, median: 9.5 dph, n = 34). The first feeding was performed at 10–12 dph for the two training centers (i.e., before the complete vitelline resorption, Morioka et al., 2013). Nevertheless, Morioka et al. (2013) indicate that feeding begins earlier in laboratory-reared larvae (5 dph at 25–30°C). Other observations showed that giant gourami larvae were able to eat brine shrimp nauplii (*Artemia* sp., authors' unpublished observations) and *Moina* nauplii (Amornsakun et al., 2014b) after 3 dph at 27–28°C and 4 dph at 28–30°C, respectively. Approximately 8 dph at 28–30°C were needed for the larvae to be able to feed on tubifex (*Tubifex tubifex*, Arifin et al., 2019). This latter live prey was the main first food used (72% of the interviewed farmers, n = 28), and other fish farmers used *Moina* sp., brine shrimp nauplii, natural plankton, poultry egg yolk, or commercial powdered fish feed as the first feed. In most cases (74%, n = 26), farmers did not change feed between the first feeding and the "nguku" stage. During this rearing period, fish were usually fed in excess. All the feeding strategies reported are summarized in Figure 5. The difficulty or the irregularity of supply in natural prey, particularly in tubifex, was considered a limiting factor for successful larval rearing by 15% (n = 5/34) of the fish farmers.

For 86% (n = 32) of fish farmers surveyed, larval rearing was performed in one step up to the "nguku" stage (i.e., 1.5–3.5 cm of total length, 2.0 ± 0.6 cm, median: 1.8 cm, n = 24). Fish farmers explained this rearing practice by the sensitivity of giant gourami larvae to handling. However, a minority of them (14%) changed larval rearing and pregrowing structures (type and/or size) one or more times with the increase of fish size until "nguku" production. Survey results demonstrated that there were six types of larval rearing structures. However, the two structures mostly used were tarpaulin tanks (39%, n = 15) from 2 to 36 m^2 and concrete tanks (31%, n = 12) from 10 to 100 m^2.

In these rearing structures, the water level ranges from 15 to 50 cm (28 ± 8 cm, n = 35) as was the case in the two training centers. Two-thirds of the interviewed farmers (66%, n = 23) reared larvae in stagnant water with occasional water renewals. Other farmers (34%, n = 12) used low continuous water flow. Water aeration was not a usual practice in giant gourami larval rearing (33% of the surveyed farmers).

Most of the surveyed farmers (70%) did not protect the larval-rearing structures against the sun or rain. Considering the low water level, it was likely that abrupt temperature variations occur. Among 39 farmers, only 5 (13%) claimed to measure the temperature during the larval rearing and the pregrowing periods. Some on-site continuous measurements with data loggers indicated that the daily temperature variation can range from 26 to 33°C in the Tasikmalaya area and from 26 to 40°C in the Bogor area (Table 3). Up to the "nguku" stage, fish were reared in traditional fish farms at a density ranging from 111 to 714 fish/m^2 (337 ± 170 fish/m^2, *median*: 306, n = 20), whereas the BPPSIGN uses and recommends an initial stocking density of 300 fish/m^2.

At the end of this rearing phase (i.e., up to the "nguku" stage), reported survival rates vary between 59% and 98% (75 ± 12%, median: 75%, n = 23; Table 6). Such values were probably optimistic and may reflect the best situation. According to fish farmers, the age at the "nguku" stage appears highly variable and ranges from 30 to 98 days (47.9 ± 15.3 days, *median*: 43.5 days, n = 36; Table 6). The two interviewed training centers indicated that

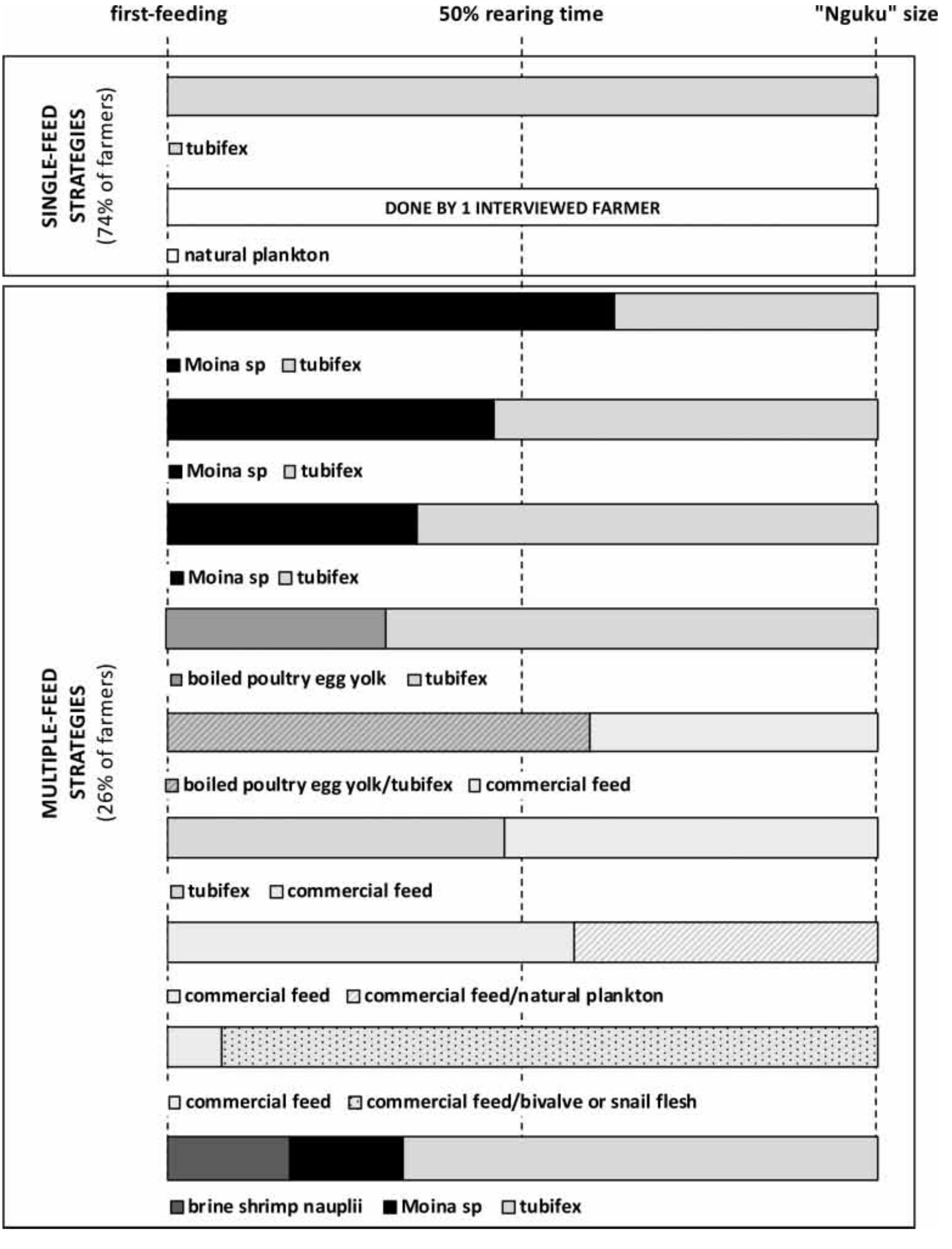

FIGURE 5 Feeding strategies for giant gourami from first feeding (10.5 ± 4.5 dph) to the “nguku” stage (47.9 ± 15.3 dph). The duration of each feeding period was normalized to take into account the variability of rearing time among farmers

60–62 days were needed to obtain “nguku”-stage fry. Interestingly, no relationship was found between size or age at the “nguku” stage and the initial fish stocking density. Final selling prices for “nguku” fry indicated by farmers interviewed were USD 2.7 ± 0.9 for 100 fish based on an exchange rate of USD 1 = IDR 14,102.

During larval rearing, 92% of the interviewed farmers (n = 35) reported frequent mortalities of giant gourami larvae. Among them, 77% (n = 27) indicated that mortalities were common during this production phase. Five farmers

TABLE 6 Summary of fry production (up to the "nguku" stage) results in giant gourami production (n = 23–37)

Rearing structures (% of the farms)	Size of the rearing structures (m^2)	Stocking density (larvae/m^2)	Estimated survival rate (%)	Size at the "nguku" stage (cm)	Age at the "nguku" stage (d)
Tarpaulin tank: 39% *Concrete tank*: 31% *Plastic tank*: 10% *Others*: 10%	2–100	337 ± 170	75 ± 12	2.0 ± 0.6	47.9 ± 15.3

Note: Reported values for survival rates are probably optimistic and may reflect the best situation.

(14%) even stated that mortalities sometimes affected 100% of the stock farmed. From the 31 responses regarding the most sensitive stage, we noted that the "gabah-kuaci" stage (15–25 dph) was the most sensitive (χ^2, p < .001).

Meteorological conditions (temperature and rain) were considered the major causes of mortality by a large majority of farmers (68% of them, n = 23). Heavy rains were frequently mentioned.

The water quality (i.e., pollution of water inflow or by dead prey, etc.) was the second main factor of larval mortality cited by 35% of farmers (n = 12). It is clear that giant gourami larval rearing can be significantly improved through better control of the rearing conditions (protection against climatic variations, monitoring water quality and temperature). In this sense, covering the basins to protect them from rainwater and carrying out incubation in tanks less prone to temperature variations were minimum recommendations to improve giant gourami larval rearing.

3.2 | Main problems faced and guidance for research

Limiting factors in egg and "nguku" production identified by fish farmers are shown in Figure 6. Meteorological factors were the main limiting factors in breeding for 50% of the farmers (n = 17). In particular, they considered that rain events led to a reduction in spawning frequency and increased the occurrence of diseases for broodfish (38%, n = 13). Interestingly, meteorological factors, and more specifically rain, were also considered the main source of problems for larval rearing (cited by 68% of the farmers, n = 23; Figure 6). However, it remained unclear whether rain acted as a direct or indirect disrupter. Generally, rainfall causes large temperature variations during this rearing phase, and results showed that only a few farmers control the temperature in their farm structures (see Section 3.1.5).

Other factors were less cited by the interviewed farmers. Thus, surprisingly, problems with water quality and pollution were only mentioned by a few farmers for both egg production (12% of the farmers, n = 4) and larval rearing (15%, n = 5). Nevertheless, our water quality measurements showed nonnegligible proportions of values outside the recommended ranges (temperature, dissolved oxygen, pH, Table 3), which suggests potential risks for larval rearing. Interestingly, noise (natural, such as from thunderstorms, or from nearby human activities) was also considered an important stressor both for broodfish (47% of the interviewed farmers, n = 16) and larvae (21%, n = 7).

Thus, all the information collected and the high variability in broodfish management by fish farmers indicated the need for examination of the effects of biotic (e.g., sex ratio, fish stocking density, frequency of fish resting periods, etc.) and abiotic (e.g., size of breeding structures, feed, meteorology, etc.) factors on sexual activity and the reproductive success of giant gourami. Such investigations may become priority topics because, paradoxically, available scientific literature in this field is currently scarce. Nutrition and disease (especially parasites, see Section 3.1.2) also required specific research efforts. In addition, the effects of external disturbances, such as natural noise or nearby human activities, have not been documented, and information is missing regarding their potential effects on spawning and egg production results.

To overcome the difficulties encountered during larval rearing up to the “nguku” stage (Figure 6), this rearing phase could be performed in closed hatcheries and ideally in a thermoregulated recirculating system. This type of system would also protect fry from predators and may provide better control over water quality, disease, and noise, also cited as limiting factors. Nevertheless, this type of system requires dedicated infrastructure and incurs additional costs that cannot be covered by most traditional fish farmers alone. In addition, the implementation of such technology requires support through technical training provided to fish farmers. These constraints make the generalization of the closed-circuit hatchery for the giant gourami complex, not necessarily adaptable and accessible to all producers. These constraints should be considered in the research objectives for aquaculture of this species. Thus, research efforts should also be directed to better determine the environmental requirements of giant gourami eggs and fry, the best conditions (with focus on the effects of water quality and especially temperature) for larval rearing, and how to adapt them to traditional farms. In parallel, research on the nutrition of juvenile giant gourami stages should be conducted to help address the food supply problems faced by farmers and optimize larval-rearing performance (growth and survival).

As a complement to the main limiting factors identified by farmers, the two training centers also listed the need to work on the genetic selection of broodfish and the nutrition from larvae to adults. In addition to these topics that can be addressed through scientific research, the training centers underlined the importance of improvement in production tools, better monitoring of the sector by authorized institutions (monitoring of farming practices and rationalization of selling prices), and better training for fish farmers.

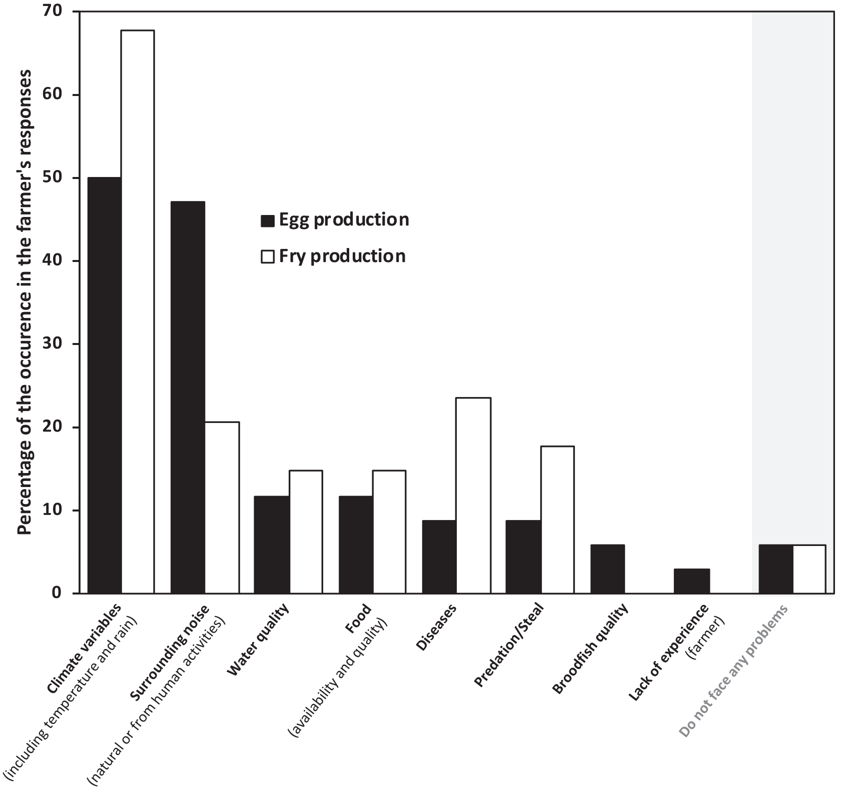

FIGURE 6 The main limiting factors identified by farmers in egg and fry production of giant gourami

3.3 | SWOT analysis of giant gourami fry production

A SWOT analysis considers the strengths and weaknesses of the internal operating environment (in this case, defined as the production of giant gourami fry) and the potential opportunities and threats from the external operating environment that may affect the sector (such as customers, markets, government policy, etc.; Leigh, 2009; Rimmer et al., 2013). Thus, based on the results of the surveys and on current knowledge regarding the giant gourami fry production chain, a SWOT analysis was carried out and is summarized in Table 7.

The SWOT analysis and the surveys showed that the production of fry of giant gourami in West Java Province, Indonesia had many strengths. This species had high heritage value and was one of the main freshwater commodities in Indonesia (Slembrouck et al., 2018). The market was therefore generally stable, with relatively high prices, although they showed some variation throughout the year. In addition, the production of giant gourami fry can be carried out using low inputs and low technology. The species can reproduce naturally in the rearing structures, allowing for relatively easy egg production on most small-scale farms. There were no particular difficulties for first feeding during larval rearing, one of the main bottlenecks generally faced in fish culture (Hamre et al., 2013), because the larvae have large vitelline reserves and oil globule (Baras et al., 2018). The production of giant gourami fry was highly integrated in local agrosystems. One of the best examples was broodfish feeding: in most cases, it was based on on-site production of planted terrestrial macrophytes such as giant taro leaves.

Nevertheless, as highlighted in this study, the production of giant gourami fry currently suffers from a lack of standardization of production techniques. The production of this relatively slow-growing fish with low fecundity, especially compared with other nonnative farmed fishes, was therefore variable and uncertain. Most fish farmers requested training and had few technical and financial resources, which further limited their ability to optimize their production. As highlighted by the fish farmers' experience, the production of giant gourami depends greatly on environmental conditions and is potentially threatened by diseases. In addition, freshwater quality and its availability are

TABLE 7 Summary SWOT table for egg and fry giant gourami production in West Java province, Indonesia

Strengths	Weaknesses
Species	Species
High heritage value	Low fecundity
Large vitelline reserves, oil globules	Low growth performance
Capable of aerial respiration	Broodfish are difficult to gender
Strong vegetarian component	
Practices	**Practices**
Low input aquaculture	Limited technical resources
Strongly integrated into local agrosystems	High variability in production methods
Natural reproduction	Lack of training for farmers
Economy/market	Economy/market
Market stability	High costs of commercial feed
High selling prices	Competition with nonnative species
	High purchase prices of broodfish
Opportunities	**Threats**
National support for aquaculture of local species	Occurrence of disease
Promotion of ecological intensification	Water quality deterioration
Improvement of fish farmer training through extension services	Increasing costs of production
Potential improvement in fry availability and zootechnical performance	

among the major problems on Java Island and affect aquaculture production. Giant gourami farming relies, to a high degree, on the farm environment. Thus, to allow the expansion of aquaculture of this species, solutions should be provided to limit the strong dependence between farming practices and the environment.

However, giant gourami aquaculture can benefit from several opportunities. For instance, there are increasing incentives from international institutions such as FAO and the Indonesian government to develop the aquaculture of local species (FAO, 2016; Tran et al., 2017). Therefore, in this context, the authorities are more inclined to support aquaculture of this species. Research programs should investigate the requirements for broodfish and juvenile stages to improve the efficiency of egg production methods and larval-rearing techniques, to completely domesticate this species (Teletchea & Fontaine, 2014). One of the strengths of the organization of the aquaculture sector in Indonesia is the existence of assistance and training services for fish farmers (called Penyuluh Pertanian Lapangan) and national production standards (SNI) that are tools for potentially more rapid dissemination of scientific research results among fish producers.

4 | CONCLUSION

This study is, to our knowledge, one of the first to describe in detail the commercial production of giant gourami (*Osphronemus goramy*) fry in Indonesian aquaculture. The production of this species, highly prized on the local market, constitutes high added value for small fish farmers in West Java and contributes to the improvement of their living conditions. The development of this production holds promises but requires an increase in research efforts on the basic biology of this species, which—despite more than a century of breeding—is not completely domesticated. Based on our analysis of the main bottlenecks, highlighted from on-farm surveys, we recommend first focusing further research on the influence of climate variables on production performance. Second, nutrition research should be performed both to improve the reproduction success of broodfish and also to provide reliable alternatives to tubifex in fry production. For the longer term, improvements in reproduction control would be needed particularly for selection programs.

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CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

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