Original Article

Assessing Broodstock Management Knowledge Among Fish Hatchery Operators: A Case Study of Rural Bangladesh

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Abstract

This study assessed the level of broodstock management expertise among fish hatchery owners in a few chosen Bangladeshi rural districts. Data were obtained from government-registered hatchery owners who had five or more years of operational experience. Knowledge was assessed using 18 open-ended questions relating to broodstock selection, nutrition and feeding management, and water quality management. Pearson's correlation and linear multiple regression analysis were used to identify knowledge and socio-economic characteristics relationships. The results showed that the hatchery owners were highly knowledgeable, with the nutrition and feeding management having the highest standardized knowledge index. Knowledge was significantly related to age, education, household size, hatchery operational area, annual income, and training exposure. Regression analysis showed that knowledge was jointly explained by age, education, household size, and training in 28.9%. Notably, knowledge acquisition was positively impacted by age, education, and training, but household size had a negative effect. These results show that hatchery owners have a great deal of experience, especially in routine operational areas, but there are still gaps in advanced scientific techniques including genetic management, broodstock selection, and environment-specific decision-making. It is advised to implement focused training programs, hands-on demonstrations, and improved extension services to increase the sustainability and productivity of hatchery-based aquaculture.

Categories: Aquaculture for sustainable food production, Aquatic animal health management

Keywords: fish hatchery owners, broodstock management, knowledge assessment, mymensingh, training, regression analysis

Introduction

One of the most rapidly expanding industries in food production on the planet is aquaculture - providing more than one-half of all fish eaten by humans - with significant influences on food security, poverty alleviation, job creation, and rural development [1]. The world population is on track to grow beyond nine billion by 2050, which will result in a sharp increase in demand of animal protein, and the focus of sustainable food production strategies will be placed on aquaculture [2]. Hatchery performance, especially through good broodstock management, is highly relevant in determining the success of aquaculture and; hence, it is important to ensure proper selection of broodfish, conditioning and nutrition, health and disease management, genetic quality, induced breeding as well as post-spawning care. It has been explained that broodstock exchange strategy has a long-term improvement effect on seed production and spawning synchrony [3]. Effective management leads to increased reproductive efficacy, fish survival, resistance to diseases, and genetic diversity of the cultured species, whereas poor management may lead to inbreeding, poor seed quality, high mortality rates, and economic losses [4,5]. Hatcheries are threatened by climatic changes, degradation of water quality, and the emergence of diseases that tend to undermine the sustainability of seed production systems [6].

This is especially the case with developing nations where limited technical knowledge, poor infrastructure, and poor extension services make them reliant on traditional, experience-based practices that tend to reduce seed quality [7,8]. These issues play a pivotal role in providing aquaculture productivity, livelihoods, and food security on a worldwide scale.

In Bangladesh, aquaculture has become one of the key factors in national food security and rural development by providing a substantial share of domestic food for fish demand and ensuring millions of homes with livelihoods [9]. The continuous development of this field relies on the active breeding of quality fish seed, which is accomplished mostly through governmental and private hatcheries [6,10,11]. Although the number of small- and medium-scale hatcheries is rapidly growing, many tend to have long-standing issues with broodstock management, such as the lack of technical expertise, poor nutrition, poor externship, poor records, and poor genetic stewardship [7,8,12-14]. These difficulties are usually aggravated by lack of training opportunities and limited access for extension services, forcing the hatchery owners to rely on traditional methods. Mymensingh is one of the major freshwater aquaculture centers, which are also densely located; there are numerous hatcheries whose seed is sold to other areas [15]. Nevertheless, there is a lack of systematic studies on hatchery owners in this region regarding their understanding of broodstock management [16,17]. Other areas of Bangladesh, such as Rajshahi, Natore, and Jashore, report substantial needs for scientific broodfish selection, nutrition, health management, genetic maintenance, and record-keeping in hatcheries [4,5].

Although existing studies have extensively examined farmers' perceptions of broodstock management, prevailing management practices, genetic considerations, and overall broodstock management status [18-22], empirical evidence that comprehensively captures farmers' actual knowledge levels remains limited. A deeper, systematic assessment is therefore needed to better understand the extent and depth of farmers' knowledge of broodstock management and to identify critical gaps that affect hatchery performance and sustainability. Assessing the knowledge of hatchery owners in Mymensingh is important, as ineffective broodstock management is associated with poor fry quality, high mortality, stunted growth, disease outbreaks, and economic losses. These vulnerabilities are further exacerbated by climate-driven variations in water temperature and water quality [4,6,11,23]. Since broodstock quality is central to hatchery productivity, fry performance, and farm profitability, a systematic evaluation of hatchery owners' knowledge of broodstock selection, nutrition, health management, genetic maintenance, water quality control, and spawning protocols is necessary. This study contributes to the existing literature by presenting the first systematic and evidence-based assessment of fish hatchery owners' knowledge of broodstock management in selected rural areas of Bangladesh, particularly in the Mymensingh region. Unlike earlier research that largely focused on operational constraints or production outcomes, this study adopts a knowledge-centered framework grounded in Bloom's taxonomy to evaluate hatchery operators' understanding across key domains of broodstock management, offering deeper insights into their technical competence and decision-making capacity. This kind of assessment will benefit with evidence and informed opinions to direct specific training interventions, extension plans, and enhance sustainability, resilience, and productivity of Bangladesh's aquaculture system [4,6,11]. Yet, no available study identified fish hatchery owners' broodstock management knowledge; therefore, the overarching objective of this paper is to evaluate the fish hatchery owners' knowledge about broodstock management in selected areas of rural Bangladesh.

In Bangladesh, fish hatcheries have been central to the success of phase V of aquaculture production by providing the constant supply of fry and fingerlings to major cultured species (carps, tilapia, and pangasius) in the last 20 years [6]. There is regional specialization and market demand, as the hatchery activities are geographically clustered in prominent clusters of these areas, such as Mymensingh, Jessore, and Rajshahi, as well as other districts of the southern regions [6]. The high growth rate of tilapia production, especially after the release of genetically enhanced tilapia strains, has greatly contributed to the abundance of seeds; however, it has also become one of the driving forces behind the problem of seed quality preservation and genetic integrity [24].

The Bangladesh hatchery industry is typified by high levels of diversity in terms of size and management potential. Although medium and large hatcheries keep their broodstock in dedicated broodstock ponds and pursue rather organized approaches to the management, medium- and small-scale individual hatcheries receive broodfish as grow-out farm products or grow-out farm ponds and fall victim to the threat of inbreeding and genetic degradation [4]. The balance between the number and the production of the hatcheries and their divisions give an additional example of the domination of the markets by private hatcheries, as Mymensingh and Rajshahi divisions produce a significant portion of national hatchlings [25].

In small and medium hatcheries, the sourcing and selection of broodstock is very informal. Whereas selective breeding, brood rotation, and planned replacement should be used, opportunistic selection and repeated utilization of the identical brood lines are widespread, resulting in diminished genetic diversity and eventual low performance [26,27]. Proper nutrition and conditioning of broodstock are also suboptimal in most hatcheries. Although high-protein diets and vitamin supplementation have been known to increase gonadal development and hatchability, low-quality commercial or farm-prepared feeds usually lead to low fecundity and hatchability [10].

Other constraints are health management and biosecurity. Disease outbreak levels in broodstock ponds may be disastrous for spawning success. The current measures to avoid quarantine, regular health screenings, and water quality estimations are usually insufficient, especially in small-scale enterprises [6,11]. Farmers claimed that they had persistent problems with the quality of post-larvae produced in the hatcheries, and their own technical insufficiency regarding the ability to gauge the health of post-larvae and stock quality increased the risk of disease and further production losses [28]. Breeding based on hormones is a common practice with carps, tilapia, and other freshwater or aquatic species, and the diverse technical knowledge about the measurement of brood maturity, dose of hormone, and manipulation of hormone-based breeding often results in poor consistency of spawning success and fry quality [29].

Genetic management is also an important problem throughout the industry. Genetic erosion due to poor record-keeping, loss of pedigree control, and widespread use of limited brood lines has made the gains in better strains through development efforts ineffective [26,27]. In addition, environmental stresses caused by climate changes such as warming, uneven rainfall, and flooding are starting to hamper nesting and survival of broodstock. Most of the owners of hatcheries do not have adaptive measures or technical resources to adequately address such emergent risks [11].

Most hatchery owners have their own hatchery system in Bangladesh, and a few of the owners depend on using leased ponds for hatchery activities [30]. At the present moment, there are 825 privately owned hatcheries, 102 government-owned hatcheries, and 124 public fish seed multiplication farms throughout the country. There are 207 hatcheries in Mymensingh district. Since 1961-1962, the government has been managing Fish Seed Multiplication Farms to ensure the supply of sufficient quantities of quality fish seed to farmers. In 2018, the total hatchling production amounted to 696,028 kg, where private hatcheries brought 674,695 kg, and 12,059 kg of the total hatchlings were produced by government hatcheries [25].

A key component of effective hatchery operations is maintaining healthy broodstock and fry through appropriate health management [30]. Despite this, many hatchery owners in Bangladesh lack sufficient technical expertise and practical experience in contemporary hatchery management [29]. It has been demonstrated that taking part in hands-on training programs on modern hatchery technology and management systems increases owners' competence, confidence, and efficiency in producing high-quality fish seed [31]. Furthermore, the Fish Farm Owners Association of Bangladesh is essential in bringing together fish farmers and hatchery owners across the country, offering group assistance to protect their legal rights and bolster their businesses [32].

In the 1960s and early 1970s, Bangladesh's aquaculture was totally dependent on fish seed that was found naturally. The availability of natural seed was drastically diminished over time by environmental stresses such habitat loss, ecosystem imbalances, climate change, and resource scarcity. As a result, there was an urgent need for organised hatchery systems and artificial breeding, which are currently the nation's main sources of fish seed [33]. Hatcheries have been essential to the growth of aquaculture in Bangladesh since the effective introduction of inexpensive artificial breeding methods in 1975 [34]. In this regard, high production and the general success of hatchery-based aquaculture depend on efficient broodstock management, which includes sourcing and selection, nutrition and feeding, health and biosecurity, and genetic maintenance.

Broodstock management is directly related to the quality of fry and survival and aquaculture productivity [10]. Although the hatchery in Bangladesh has grown to a considerable amount, knowledge levels among hatchery owners are not uniform and often insufficient [16]. It was revealed that few hatchery operators are informed on the rudimentary broodstock management practices and do not adhere to any principles or guidelines in the selection of sufficient-sized breeders, hypophysation dosage delivery, and mating without relative paternity between the male and female spawners in Jessore region of Bangladesh [35]. Many hatchery owners rely on noticeable visual characteristics such as the size and maturity instead of genetic quality or health status [4]. Unplanned sourcing raises the risks for inbreeding and decline in long-term performance of seed [29]. Balanced feed can improve the reproductive performance of the fish, but unfortunately, hatcheries often utilize low-cost feed that does not have the correct nutrient composition [16]. Studies do corroborate that better hatchability and larval survival occur where better feeding practices are put into practice [27].

Biosecurity is still poor in most hatcheries, with little quarantine procedures, rare disease inspection, and poor management of water quality [6]. It has been demonstrated that training interventions greatly enhance the health management of broodstock [10]. Errors in hormone dosage and badly timed injections are common among untrained hatchery operators [29]. Post spawning care practice also needs improvement [16]. Systematic record-keeping is uncommon amongst small hatcheries, which contributes to genetic breakdown and an inability to measure the performance of hatcheries over time [27]. Accurate record-keeping among hatcheries results in better seed qualities [4].

Knowledge and adoption of improved practices are influenced by different factors such as education, income, training, capacity to invest, and availability of extension services [6,11]. Small-scale operators tend to focus more on short-term versus long-term concerns for broodstock management to optimize profits. Most hatchery owners have no knowledge of implementing climate-adaptive broodstock management strategies despite a growing environmental variability [10]. This study was conducted in seven unions of the Tarakanda subdistrict of the Mymensingh region of Bangladesh. Through three interrelated goals, we examine the hatchery owners' comprehension of broodstock management. The study's initial goal is to determine the extent of their knowledge and explore how it relates to selected socio-economic and operational characteristics. Second, it seeks to identify the key factors that influence the owners' level of knowledge in broodstock management.

Materials And Methods

Study area, population and sampling

The study was conducted in seven unions of Tarakanda Upazila of Mymensingh because of the region's significant number of fish hatcheries. The selection of Upazila was based on suggestions provided by the Senior Upazila Fisheries Officer of Mymensingh Sadar and Tarakanda Upazilas of Mymensingh district. A population list was prepared with the assistance of the Senior Upazila Fisheries Officers of Sadar and Tarakanda Upazilas, along with several local hatchery owners. A total of 144 hatchery owners from different unions of Tarakanda Upazila formed the study population. The population list was prepared based on the following two criteria:

i) Hatchery owners with a minimum of five years' experience in hatchery operations.

ii) Hatcheries that have a government registration.

The sample size was determined using Slovin's formula [36]:

$$n = N/(1 + Ne^2)$$

where, n = sample size = 105, N = population size = 144, and e = margin of error (expressed as a decimal) = 5% at 95% confidence level. Stratified random sampling was used, dividing the population by union and hatchery size, and selecting a proportional sample of 105 owners. Random selection within each stratum ensured representativeness and minimized bias.

Data collection method and tool

Face-to-face structured interviews were conducted with fish hatchery owners in 2025.

Measurement of the dependent variable

Three aspects of broodstock management, namely identification and selection of broodstock, nutrition and feeding management, and water quality management, were selected based on a review of the literature and insights from Key Informant Interviews (KIIs) with Upazila Fisheries Officers, hatchery owners, and hatchery in-charges of the Bangladesh Fisheries Research Institute. For each aspect, six open-ended questions were developed, covering all cognitive levels of Bloom's taxonomy [37] revised by Anderson [38] and Krathwohl [39]. In total, 18 questions were designed across the three aspects, with scores assigned to each question based on its importance, difficulty, and depth of knowledge. Respondents could receive full marks for a correct answer, half marks for a partially correct answer, and zero for an incorrect answer. Thus, the knowledge score of a respondent could range from 0 to 67. Both linear and stepwise multiple regression models were used to analyze the data.

The factors that may influence the knowledge of the respondents about the broodstock management were identified and measured by correlation and linear regression analysis. The data were coded and analyzed with the statistical package for social science (SPSS) version 20. Pearson's product correlation coefficient (r) [40] was computed using the following formula:

$$r_{xy} = \frac{\sum(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum(x_i-\bar{x})^2\sum(y_i-\bar{y})^2}}$$

where, r_{xy} is the Pearson's product-moment correlation coefficient, and x and y are the means of the variables x and y, respectively.

Multiple linear regression analysis (enter method and step wise) was used to determine the factors contributing to knowledge of fish hatchery owners about broodstock management.

$$y_i = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + \beta_7X_7 + \beta_8X_8 + \beta_9X_9 + \beta_{10}X_{10} + \beta_{11}X_{11} + \beta_{12}X_{12} + \in_i$$

where, y = hatchery owners' knowledge about broodstock management, β = slopes associated with independent variables, β_0 = constant, X_1 = age, X_2 = level of education, X_3 = household size, X_4 = hatchery management experience, X_5 = farm size, X_6 = area under hatchery, X_7 = annual family income, X_8 = access to credit, X_9 = total investment at hatchery, X_{10} = training on hatchery management, X_{11} = extension media contacts, X_{12} = organizational participation, and $\in_i$ = Error term

Results And Discussion

Salient features of fish hatchery owners

Table *1* explains the salient features of fish hatchery owners. Most hatchery owners were in the middle age group (58.1%), with a mean age of 40.99 years; thus, broodstock management is dominated by economically active people. Just under one-half of respondents (48.6%) belonged to the category of secondary school education (mean 5.58 years). The average household size was 5.86, and the largest proportion of households were medium (43.8%) in size. Although 53.3% of the respondents exhibited low experience, the mean experience was 11.85 years. Most of the hatchery owners were running marginal to small farms, with a mean owned area of 0.26 ha, reflecting the marginal nature of hatchery operations in Bangladesh. The majority of the respondents (89.5%) are running hatcheries on small areas, which implies intensive use of limited land resources. More than 9 in 10 (94.3%) belonged to the high-income category (mean income: BDT 677.3 thousand). Access to credit was low; in fact, 30.4% of the respondents had no access to credit. Most of the hatchery owners (69.5%) reported high level of investment, with mean level of investment at BDT 666 thousand. Nearly one-half of the respondents (47.6%) had medium-duration training (average, 12.73 days). A majority of hatchery owners (93.3%) had medium extension media contact (regularly exposed to advisory services). More than half a number of the respondents (56.2%) were observed with low organizational participation (3.90 years).

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Characteristics	Score range		Respondent (n = 105)			Mean	SD
	Possible	Observed	Category	No.	%		
1. Age (Years)	Unknown	26-59	Young (up to 18-35)	36	34.3	40.99	9.24
			Middle-aged (36-55)	61	58.1		
			Old (above 55)	8	7.6		
2. Level of education (Years)	Unknown	0.5-12	Can sign only (0.5)	22	21.0	5.58	3.34
			Primary level (1-5)	28	26.7		
			Secondary level (6-10)	51	48.6		
			Higher secondary (11-12)	4	3.7		
3. Household size (Number)	Unknown	3-9	Small (2-4)	19	18.1	5.86	1.36
			Medium (5-6)	46	43.8		
			Large (above 6)	40	38.1		
4. Hatchery management experience (Years)	Unknown	5-26	Low (up to 8)	56	53.3	11.85	5.17
			Medium (8-14)	46	43.8		
			High (above 14)	3	2.9		
5. Farm size (Hectare)	Unknown	0.016-0.95	Marginal (0.001-0.19)	60	57.1	0.26	0.25
			Small (0.2-0.99)	45	42.9		
			Medium (1-2.99)	0	0		

			Large (3 above)	0	0		
6. Area under hatchery operation (Hectare)	Unknown	0.02-6.02	Small (less than 0.5)	94	89.5	0.22	0.202
			Medium (0.5-5.0)	6	5.7		
			Large (above 5.0)	5	4.8		
7. Annual family income ("000" BDT)	Unknown	135-1,780	Low (up to 500)	2	1.9	677.3	320.7
			Medium (500-1000)	4	3.8		
			High (above 1000)	99	94.3		
8. Access to credit ("000" BDT)	Unknown	0-400	No Credit (0)	32	30.4	107.2	106.4
			Low (less than 150)	42	40.0		
			Medium (150-300)	26	24.8		
			High (above 300)	5	4.8		
9. Total investment at hatchery ("000" BDT)	Unknown	120-2,250	Low (less than 150)	13	12.4	666	529.7
			Medium (150-300)	19	18.1		
			High (above 300)	73	69.5		
10. Training on hatchery management (Days)	Unknown	6-28	Low (up to 13)	43	41.0	12.73	5.1
			Medium (14-21)	50	47.6		
			High (above 21)	12	11.4		

11. Extension media contact (Score)	0-33	10-23	Low (up to 11)	5	4.8	15.70	3.12
			Medium (12-22)	98	93.3		
			High (above 22)	2	1.9		
12. Organizational participation (Years)	Unknown	0-26	No (0)	30	28.6	3.90	3.77
			Low (1-8)	59	56.2		
			Medium (9-17)	13	12.4		
			High (above 17)	3	2.8		

TABLE 1: Salient feature of the hatchery owners' knowledge about broodstock management

SD = Standard Deviation; BDT = Bangladeshi Taka (1 BDT = 0.008$)

Extent of knowledge about broodstock management

The distribution of fish hatchery owners' knowledge of broodstock management is organized into two subsections:

i. Across different aspects of broodstock management

ii. Blooms taxonomy-based knowledge level

To explain the comparative knowledge of fish hatchery owners' about broodstock management, a knowledge index was computed. As the scores were not from equal possible scores, standardized scores are required for comparison. Hence, a Standardized Knowledge Index (SKI) for a level of knowledge was determined by the following formula: SKI = (CS/PS) × 100, where, SKI = Standardized Knowledge Index for a component, CS = Sum of the computed scores obtained by all the respondent hatchery owners, and PS = Sum of the possible scores for all the respondent hatchery owners.

The distribution of knowledge scores among three major areas of broodstock management is shown in Table 2. The SKI showed variation across different aspects of broodstock management. Nutrition and feeding management scored highest (SKI = 74.11), followed by water quality management (SKI = 72.50) and identification and selection of broodstock (SKI = 72.07). Table 3 shows that Bloom's taxonomy-based analysis indicated the highest knowledge at the "Remembering" level (SKI = 91.27), followed by Evaluating (SKI = 80.37), Analyzing (SKI = 78.33), Understanding (SKI = 76.46), Creating (SKI = 76.06), and Applying (SKI = 67.62). Data of Table 4 present most hatchery owners (80.95%) had high overall knowledge (>42), 12.38% had medium knowledge (12-42), and 6.67% had low knowledge (1-21).

Factors influencing the knowledge of fish hatchery owners about broodstock management

Correlation Analysis

Pearson's product moment coefficient of correlation (r) was employed to test the null hypothesis for the relationships between two variables. Level of probability was used as the basis for rejecting the null hypothesis was 5% (0.05). The results of correlation of coefficient test between the explanatory and focus variables are shown in Table 5. Among 12 independent variables, age, level of education, area under hatchery, annual family income, and training on hatchery management applied positively and significantly to hatchery management knowledge, but the household size had a negative impact.

Aspect	Sum of computed scores for an aspect of knowledge (CS)	Mean	Sum of possible scores for an aspect of knowledge (PS)	Standardized knowledge index (SKI)
Identification and selection of broodstock	1,665	15.86	2,310	72.07
Nutrition & feeding management	1,712	16.30	2,310	74.11
Water quality management	1,752	16.67	2,415	72.5

TABLE 2: Distribution of total knowledge scores across different aspects of broodstock management (n = 105)

Level of knowledge	Sum of possible scores for a level of knowledge (PS)	Sum of computed scores for a level of knowledge (CS)	Mean	Standardized knowledge index (SKI)
Remembering	630	575	5.48	91.27
Understanding	735	562	5.35	76.46
Applying	1,050	710	6.76	67.62
Analyzing	1,260	987	9.40	78.33
Evaluating	1,365	1,097	10.45	80.37
Creating	1,575	1,198	11.41	76.06

TABLE 3: Bloom’s taxonomy-based knowledge level of fish hatchery owners on broodstock management (n = 105)

Category	Hatchery owners (n = 105)		Mean	Standard deviation
	Number	Percent (%)		
Low knowledge (1-21)	7	6.67	48.85	3.35
Medium knowledge (12-42)	13	12.38		
High knowledge (above 42)	85	80.95		
Total	105	100		

TABLE 4: Distribution of the fish hatchery owners according to their knowledge level about broodstock management

Dependent variable	Selected characteristics	Correlation coefficient (r) with df 103
Fish Hatchery Owners' Knowledge About Broodstock Management	Age	0.243*
	Level of education	0.276**
	Household size	-0.223*
	Hatchery management experience	-0.151
	Farm size	-0.029
	Area under hatchery	0.269**
	Annual family income	0.206*
	Access to credit	-0.115
	Total investment at hatchery	0.036
	Training on hatchery management	0.244*
	Extension media contacts	-0.052
	Organizational participation	-0.079

TABLE 5: Correlation between selected characteristics and the fish hatchery owners' knowledge about broodstock management (n = 105)

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

Econometric Estimation of Factors Influencing the Knowledge of Fish Hatchery Owners About Broodstock Management

The multiple regression analysis (Table 6) found that age, level of education, household size, and training on hatchery management were the significant determinants of knowledge regarding broodstock management by the hatcheries owners and were found to explain 28.9% of the variation (R2 = 0.289). To understand individual contribution of the aforesaid explanatory variables, stepwise multiple regressions was conducted, and the results are shown in Table 7.

The multiple regression analysis showed a progressive increase in the explanatory power of the model with the sequential inclusion of socio-economic variables using hierarchical analysis. In the first step, the level of education alone explained 6.7% of the adjusted variation in the knowledge of hatchery owners, which is considered to be the basis of owners' knowledge in the technical field. The inclusion of training in hatchery management in Model 2 led to an increase in the explained variation by 4.5%, indicating that capacity-building activities, both formal and informal, play a major role in providing information over and above educational attainment. In Model 3, the inclusion of household size also improved the model fit, and this contributed an additional 5.8% to the explained variance. This result suggests that household labor availability and family responsibility could affect managerial engagement and experiential learning in hatchery operations. The final model included age, which proved to be the most important additional predictive variable, as it showed an increase of 11.7% in the adjusted variation explained. This substantial contribution raises pivotal issues concerning the significance of accumulated experience and long-term immersion in hatchery practices for the robustness of technical knowledge.

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Independent variables	Unstandardized coefficients		Standardized coefficients	t	Sig
	B	Std. Error	Beta		
(Constant)	43.972	5.649		7.784	0.000
1. Age	0.264	0.095	0.300	2.785	0.007
2. Level of education	0.467	0.215	0.199	2.178	0.032
3. Household size	-1.452	0.606	-0.272	-2.398	0.018
4. Hatchery management experience	-0.310	0.191	-0.221	-1.624	0.108
5. Farm Size	-0.804	2.757	-0.027	-0.292	0.771
6. Area under hatchery operation	2.912	1.780	0.188	1.635	0.105
7. Annual family income	0.003	0.002	0.178	1.837	0.069
8. Access to credit	0.010	0.069	0.014	0.139	0.890
9. Total investment at hatchery	-0.011	0.008	-0.125	-1.297	0.198
10. Training on hatchery management	0.317	0.147	0.224	2.164	0.033
11. Extension media contact	-0.272	0.300	-0.117	-0.905	0.368
12. Organizational participation	-0.113	0.138	-0.078	-0.818	0.415
Adjusted R^2 =0.289, F-value = 4.517					

TABLE 6: A summary of the linear multiple regression analysis explaining the focus variable

Model	Combination of the factors	Multiple R	Multiple R^2	Adjusted R^2	Variation explained (%)
1	Constant + Level of education	.276	0.076	0.067	6.7
2	Constant + Level of education + Training on hatchery management	.368	0.135	0.112	4.5
3	Constant + Level of education + Training on hatchery management + Household size	.448	0.201	0.170	5.8
4	Constant + Level of education + Training on hatchery management + Household size + Age	.536	0.302	0.287	11.7

TABLE 7: A summary of the stepwise multiple regression analysis

The research found that most of the fish hatchery owners in Bangladesh are middle-aged, with a mean age of 40.99 years, and this means that broodstock management is controlled by the economically active members of the society. Experience accumulation and use of technology in the aquaculture systems are positively correlated with age [41,42]. Almost 50% of the respondents demonstrated technical knowledge, information processing, and management of broodstock [43]. The household size tended to be medium, and it affects the labor availability and intensity of management in aquaculture-based businesses [14]. Despite the fact that more than half of the participants had low levels of hatchery experience, the average experience of 11.85 years confirms the idea of better broodstock selection, conditioning and spawning success [44,9]. Majority of hatcheries were marginal or small, with a mean area of 0.26 ha that captures the small-scale process of hatcheries in Bangladesh, affecting the production potential and investment options [14,45]. The high-income level of the majority of the participants (mean BDT 677.3 thousand) enhances the ability to invest in quality broodstock, feed, and infrastructure [9]. Some of the owners (30.4%) may have limited access to credit, which limits the adoption of advanced technologies and maintenance of broodstock quality [46]. Infrastructure and broodstock management practices are supported by high investment in the hatchery (mean BDT 666 thousand). Medium-duration training (12.73 days on average) enhances the technical competence of broodstock nutrition, health, and breeding [47], whereas the media contact at the medium level facilitates the spread of information and innovations [48]. Reduced organizational participation (mean 3.90 years) can help lower the access to collective learning and institutional support [49].

Knowledge assessment revealed that hatchery owners demonstrated the highest competence in nutrition and feeding management and water quality management, while broodstock identification and selection had the lowest knowledge score. Differences in total and mean scores indicate that at least some of the differences lie in the range of scoring applied to the various aspects, and this means that the SKI is a more valid basis for comparison, as it standardizes the scores on a common scale. Among the aspects, nutrition and feeding management registered the highest SKI (74.11), signifying comparatively higher knowledge regarding types of feeds, frequency of feeding, rationing, and nutritional requirements of broodstock. This can be explained by the routine nature of feeding practices, experience, and frequent contact with extension advice. Water quality management came second (SKI = 72.50), as there is good hands-on knowledge of key parameters (dissolved oxygen, pH, temperature, and ammonia) as a result of ongoing monitoring and operational problem-solving. In contrast, identification and selection of broodstock showed the lowest SKI (72.07), which indicated the limitations in the higher order of knowledge involved in genetic selection, health screening, and broodstock improvement, which usually require the involvement of formal training and scientific understanding. In sum, higher cumulative scores at the creating level indicate the practical orientation of hatchery owners, in that such items highlighted actual world problem troubleshooting and management planning. Overall, the findings suggest hatchery owners possess greater competence in operational and experience-based areas of broodstock management than technical ones, making the need for specific capacity-building interventions related to scientific broodstock selection and genetic quality management.

Bloom's taxonomy analysis showed the highest scores at the "Remembering" level (SKI = 91.27), reflecting a good level of factual knowledge and awareness of basic broodstock management practices such as recognition of mature brood fish, maintenance of water quality, and feeding regimes. This high score can be explained by long-term hands-on experience in hatchery practices, reinforcing basic concepts through repeated observation and application. In addition, the relatively high percentage of respondents who had a secondary level of education and some exposure to previous training was likely to improve their ability to retain cognitive elements of basic technical information. These results are comparable with previous research findings [35], where high levels of knowledge were observed among previously educated and trained hatchery operators. In contrast, comparatively lower scores were recorded at the "Applying" and "Analyzing" levels, showing that even if hatchery owners can recall and comprehend technical information, they struggle with the interpretation of complex issues, including genetic broodstock management and advanced decision-making related to disease diagnosis and handling variable environmental conditions in the farming environment.

The high degree of knowledge exhibited by the hatchery owners can be attributed to their positive socio-economic characteristics. Most of the respondents were middle-aged (36-55 years), giving some practical experience, and almost half had a secondary education level, which facilitated their understanding of technical issues. Higher income, increased size of hatchery operation, and access to training further served to facilitate exposure to information, resources, and more improved management practices. Overall, the results indicate that hatchery owners have a solid base of knowledge on broodstock management, based primarily on experience, with some technical training; however, there is an obvious need for continuous, practical capacity-building programs focusing on application-oriented and analytical capabilities to enhance scientific broodstock management practices. These results are similar to those from other studies [5,50], which have demonstrated that better-educated and more experienced hatchery owners have greater knowledge of broodstock management and breeding techniques.

Correlation analysis showed positive relationships between knowledge and age, education, hatchery area, family income, and training, whereas household size had a negative effect. The same trends have been cited in other studies. The available experience and long use of the hatchery activities also contribute to the increase in knowledge with age [51], and a positive correlation between age and the knowledge of technologies is also observed in Bangladesh among fish farmers [52]. Education positively influences the cognitive capacity, exposure to scientific knowledge, and willingness to use the extension services, which consequently improves the knowledge about broodstock selection, feeding, and water quality management [53,54]. Knowledge had a negative relationship with the household size; the number of family members can reduce the time and other resources necessary to obtain technical knowledge [55,56]. The size of the hatchery was found to have a positive impact on knowledge, and it is possible to state that bigger hatcheries are more technical and information-related [6]. There was an additional positive correlation between a higher family income and knowledge, which demonstrates a higher level of access to education, training, and modern management practices [6,57]. Training was found to be a very important element in knowledge development, as it solidifies the idea of it serving as an effective method of spreading technical skills in hatchery management [16,58].

Multiple regression analysis confirmed that age, education, household size, and training were significant determinants of knowledge, explaining 28.9% of the variation. The positive and significant effects of age and level of education indicate that the accrual of experience and education contribute to increasing the knowledge about broodstock management [41,51,59]. The significant positive effect of age suggests that broodstock management knowledge increases with maturity and accumulated experience, as most hatchery owners belong to the economically active middle-aged group and gain skills through prolonged operational involvement and decision-making. Similarly, secondary-level education enhances their ability to understand technical information on nutrition, health, breeding, and record-keeping, thereby improving their analytical capacity and the adoption of scientifically recommended management practices.

Conversely, household size significantly influenced the negative aspect, which is probably explained by more financial and time constraints, restricting the involvement in management and extension processes [60]. Although most respondents came from medium-sized households, increased family responsibilities often create financial and time pressures that limit hatchery owners' engagement in training, extension, and information-seeking activities, thereby reducing opportunities to improve and update their broodstock management knowledge.

Furthermore, training on hatchery management was significantly effective and had a positive effect, as shown by the practical and hands-on training methods in enhancing broodstock management expertise [4,5,59]. Nearly half of the hatchery owners had participated in medium-duration training programs, offering practical exposure and structured technical guidance that helped bridge the gap between theory and practice. This highlights the crucial role of focused, skill-based training in strengthening broodstock management expertise.

Conclusions

This research evaluated the degree and factors of broodstock management knowledge among the fish hatchery owners in Mymensingh, Bangladesh, and it was found that there were comparatively good knowledge levels in routine and experience-based areas of knowledge of nutrition, feeding, and basic water-quality management, but significant deficiencies in scientifically advanced fields such as broodstock identification, genetic quality maintenance, and environment-specific decision-making. Age, education, and technical training played a major role in influencing the difference in knowledge, whereas a greater household size had a negative impact on knowledge gaining, particularly between socio-economic limitations and managerial capacity. The results indicate that experiential learning in hatchery practices is a critical element of operation in the country of Bangladesh, and as much as it is an effective aspect, it falls short in tackling new challenges that are associated with genetic decline, disease-prone and varying climatic conditions. Therefore, to improve scientific broodstock management and assure sustainable seed production, application-driven and focused training, enhanced extension services, and dialogue institutional engagement are needed.

Despite its contributions, the study has limitations due to the scope of the study being a single region, self-reported data, and cross-sectional study design, which limits generalizability and cause and effect inferences. Future studies ought to be multi-regional, longitudinal, and include biological and performance indicators to have more favorable associations between knowledge levels and hatcheries. All in all, enhancing technical abilities, strengthening extension systems, and empowering supportive policy frameworks are essential for improving broodstock management and ensuring the long-term sustainability of hatchery-based aquaculture in Bangladesh.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Disclosures

Plant subjects: All authors have confirmed that this study did not involve any herbarium specimen. **Human subjects:** Consent was obtained or waived by all participants in this study. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

Data Availability Statements

The datasets (and/or code) supporting this study are available from the corresponding author upon reasonable request.

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