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Zootechnical Factors Affecting the Biosecurity Profile of Fish Farms in the Centre Region of Cameroon

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Abstract

To optimize fish production by a better knowledge of preventive measures against fish diseases, a cross-sectional audit was carried out in Cameroon from March to April 2022 on the zootechnical factors affecting the biosecurity practice in fish farms from the Centre Region (3°55'-4°67'N; 9°46-11°52' E). A total of 50 farms were selected using the "snowball" method, face-to-face interviews of fish farmers using a semi-structured questionnaire, and direct observation. The most practiced farming system was the semi-intensive production system (74%), non-integrated fish farming (100%), grow-out (66%), monoculture (54%), and the soil system (34% of farms with ponds). The compliance rate (40.98%) and adoption rate (41.00%) of biosecurity measures (BM) were intermediate. The most adopted BM were "sanitary lock" and "no exchange of materials with other farms", while the least adopted was "veterinary intervention", "dead fish incinerated" and "special outfit for visitors". The BM was significantly more observed in intensive, nursery farms and those whose culture facilities were fastanks + concrete tanks with 3 to 12 production cycles per year. A strong, positive, and significant linear relationship was established between the compliance rate (y) and BM such as the protection of farms from wild animals, quarantine of new fish, and number of production cycles per year (x). The linear regression model between y and x was y = 4.65x - 0.0417. The capacity of fish farmers should be built on biosecurity practices.

INTRODUCTION

To satisfy the high annual demand for fish estimated at 500,000 tonnes, Cameroon imports almost 50% (250,000 tonnes) of national demand to supplement domestic production, estimated at 335,000 tonnes/ year, of which 95% (318,250 tonnes) comes from fishing and only 5% (16,750 tonnes) from fish farming (MINEPIA, 2021). The low contribution of fish farming to national production contrasts with Cameroon's

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natural endowments namely a dense hydrographic network, floodplains, marshes, and numerous sites with high fish farming potential (Kenfack *et al.,* 2019). The rationale of the contrast is that, besides the constraints related to the high cost and scarcity of fish feed on the market, fish are subject to multiple diseases capable of destroying the entire production on the farm. The main cause of disease outbreaks on a farm is failure to comply with biosafety measures (Racicot and Vaillancourt, 2009).

FAO (2007) defines biosecurity as a strategic and integrated approach that encompasses policy and regulatory frameworks to analyze and manage risks relevant to human, animal, and plant life and health, including associated environmental risks. Aquaculture biosecurity includes control of the spread of aquatic plant and animal diseases and invasive pests, and the production of products that are safe to eat. Obosi and Agbeja (2015) highlighted that biosecurity is an essential tool to reduce the risk of diseases entering a farm. Additionally, suitable biosecurity practices can prevent emerging health issues, reduce the impacts of disease, and improve profitability. Once the disease occurs, the treatment becomes technically and financially more demanding.

In Cameroon, very little work has been done on mapping biosecurity practices on fish farms (Ngueguim et *al*., 2020; Fonkwa et *al.,* 2022; Fonkwa et *al.,* 2023a and b). Better knowledge of biosecurity practices and their influencing factors could improve fish health and production, hence the need for such a study in the Centre Region, a major fish production area in Cameroon. This study aims to determine the zootechnical characteristics of fish farms in the Centre Region of Cameroon and their effects on the implementation level of biosecurity measures.

METHODOLOGY

Ethical Approval

The study does not report results from an experiment on animals or humans.

Place and Time

The study was conducted from March to April 2022 in five Divisions (Lekie, Mefou-and-Afamba, Mefou-and-Akono, Mfoundi, and Nyong-and-So'o) of the Centre-Region-Cameroon (Figure 1) with significant fish farming activity. The Centre Region is located between 2°47'13"- 6°57'28" North latitude and 11°40'00"- 14°00'15" East longitude at 602 m above sea level. The climate is of equatorial type and characterized by a bimodal rainfall regime with short (March-June) and long (August-November) rainy seasons alternating with two dry seasons. The average annual rainfall is between 1500 and 2500 mm while the temperature is around 23.5°C. The ferralitic soils have low organic matter content, a variable clay level (40 - 60%), and an acid pH (4.5 to 5.5) (CIRAD, 2013).

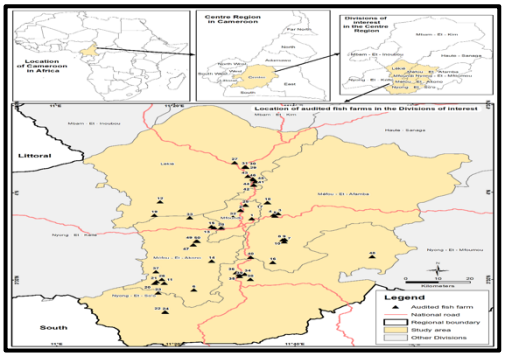

Figure 1. Location of audited fish farms in the Centre Region of Cameroon.

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Research Materials

Given that this is a diagnostic research or audit, special laboratory materials were not necessary. The only devices used for the audit of fish farms were a computer (HP Intel Core i7 8Go SSD256, USA) and a mobile phone (Tecno Spark 7, VC: 33147, D/N: M6N11, China).

Research Design

A total of 50 farms were selected, coded, and audited using the "snowball" method (Delaunay *et al.,* 2008; Kone, 2015). This method consisted to select randomly the first farm in a locality with the help of local veterinary health officials and inspection after briefly presenting the importance of the survey to the manager of the farm concerned. Subsequently, the manager was asked to facilitate the flow of the survey by indicating the geographical location of another farm and so on until the entire area was covered (Thierry, 2009). Eligibility criteria for fish farms took into consideration road accessibility, functional status, and availability of the farm manager to participate in the study (Racicot and Vaillancourt, 2099). The data were collected face-to-face by interviewing the managers of the fish farms using a semi-structured questionnaire i;e; comprising both closed and opened question sets; and through the personal observation of the researcher.

Work Procedure

Questionnaire Design

The questions were grouped into two parts. The first part included questions related to the zootechnical characteristics of the fish farms (reared species, production system, culture facilities, culture phases, number of production cycles per year, etc.), and the second part was composed of 24 biosecurity measures that could be implemented in the audited farm, for example, the use of footbaths, the incineration of death fish, etc (the tables in this manuscript include all the questionnaire items). Those measures were grouped into three major components namely isolation (7 measures), traffic management (3 measures), and sanitation (14 measures) (Arthur *et al*., 2008; Kouam and Moussala, 2018; Wanja *et al.,* 2020). Before starting the present study; the questionnaire was pre-tested by interviewing a subsample of 10 randomly selected fish farmers using the "snowball" method as previously described. The objective was to verify the accuracy, relevance, consistency, redundancy, and clarity of the questions to make subsequent adjustments if necessary (Kouam *et al.,* 2019). The geographic coordinates of the farms were recorded using Global Positioning System (GPS) software.

Biosecurity Scoring System

The binary scoring system or weighting system was used by assigning 1 and 0 respectively to the implemented biosecurity measure or not. For instance, if a farm implemented a biosecurity measure like the use of footbaths, the value 1 would be assigned to the farm. On the contrary, the farm would score the value 0 for the use of footbaths. The final score of a farm was the sum of all the values recorded in the farms (0 or 1 per measure). Given that a biosecurity component (isolation, traffic control, and sanitation) included several measures, the mean score of a component was obtained by adding up the scores of individual measures. Thereafter, the total score was divided by the total number of measures within the component. The isolation component for instance had 7 measures while the components related to traffic control and sanitation were made up of 3 and 14 measures respectively as illustrated in Table 3 (Kouam and Moussala, 2018).

The maximum score of a given measure and farm was respectively 50 (overall number of fish farms) and 24 points (overall number of biosecurity measures). The biosecurity measures were weighted equally (linear scoring system). Any biosecurity measure was estimated to be less efficient in transmitting and occurring a disease since fish may suffer from poor health due to the lack of implementing biosecurity

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measures. The main concern of this study was the importance of implementing biosecurity measures on the health of cultured fish and not the risk level generated by the lack of implementing each biosecurity measure as is the case in disease transmission pathways (Can and Altug, 2014; Gelaude *et al.*, 2014; Maduka *et al.*, 2016).

Evaluation of the Compliance and Adoption Rates of Biosecurity Measures and Data Analysis

The compliance rate (CR) and adoption rate (AR) of biosecurity measures were calculated (Racicot and Vaillancourt, 2009).

$$CR = \frac{\text{number of measures applied by a farmer (total score of the farm)}}{\text{Total of recommended measures}} x100$$

$$AR = \frac{\text{number of farms applying a biosecurity measure (total score of the measure)}}{\text{Total number of audited farms}} x100$$

For example, of the 24 biosecurity measures, if a given farm implemented only 6 measures, the CR for that farm would be 6/24 x 100 = 25%. Also, if 5 farms out of 50 farms used the footbaths, the AR of that biosecurity measure (use of footbaths) would be calculated as follows: 5/50 x 100 = 10%.

The ranking of the compliance rate (Low, intermediate, high) used by Racicot and Vaillancourt (2009) was applied to the adoption rate to classify fish farms (Table 1).

Table 1. Classification of fish farms according to the compliance rate of biosecurity measures.

CR	Implementation level	Biosecurity practice/status	Risk ranking	Type of farms
[0-25]	Low	Poor	Major	A
]25-75]	Intermediate	Intermediate	Moderate	B
]75-100]	high	Good	Minor	C

CR : Compliance Rate.

Data Analysis

The zootechnical characteristics, compliance, and adoption rates were subjected to descriptive statistics using the R software package. The Kruskal-Wallis K test, the Mann-Whitney test (U), or the analysis of variance (F) depending on the type of data sets were used to compare the values of compliance and adoption rates expressed as mean ± standard deviation according to the zootechnical characteristics of farms and their geographical location. A multivariate linear regression model was used to determine a possible relationship or association between the compliance rate and the zootechnical characteristics of fish farms. The significance level (p) was set at 0.05.

RESULTS AND DISCUSSIONS

Zootechnical Characteristics of Fish Farms in the Centre Region

As summarized in Table 2, catfish (*C. gariepinus*) was the most reared species regardless of Divisions. The most common farming system was semi-intensive. Monoculture predominated over polyculture. Non-integrated fish farming was the most encountered. The most common culture phase (Grow-out) accounted for up to 66% of the audited farms. The ground-based system was the most practiced (34% of pond farms). The highly diversified non-ground system was represented by fastanks and concrete tanks. Most farms (48%) used a combination of locally manufactured and imported feed.

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Table 2. Farms frequency distribution (%) according to the zootechnical characteristics in the Centre Region of Cameroon.

Zootechnical Characteristics	Farms' administrative location (Divisions)					
	Lekie (n=10)	Mfoundi (n=8)	Mefou-and-Afamba(n=12)	Mefou-and-Akono(n=10)	Nyong-and-So'o (n=10)	Overall (N=50)
Fish species reared						
Clarias gariepinus	100	100	100	100	100	100
Cyprinus carpio	0	25	41.66	10	10	18
Heterotis niloticus	0	25	41.66	30	0	20
Oreochromis niloticus	40	50	58.33	40	40	46
Parachana obscura	0	25	8.33	0	10	8
Production systems						
Intensive	30	25	16.66	30	30	20
Semi-intensive[1]	60	75	66.66	70	70	74
Extensive	10	0	16.66	0	0	6
Type of culture						
Monoculture[2]	60	50	58.33	50	50	54
Polyculture[3]	30	25	41.66	40	40	36
Monoculture+polyculture	10	25	0	10	10	10
Integrated farming[4]						
Yes	0	0	0	0	0	0
No	100	100	100	100	100	100
Culture phases						
Nursery	10	12.50	0	10	0	06
Grow-out	80	50	58.33	70	60	66
Nursery + grow-out	10	37.50	41.66	20	40	28
Culture Facilities						
Ponds	40	12.50	50	30	30	34
Fastanks	30	12.50	8.33	10	10	14
Concrete tanks	10	12.50	0	10	0	06
Ponds + fastanks	10	25	16.66	20	10	16
Ponds + concrete tanks	0	25	8.33	10	40	16
Fastanks + concrete tanks	0	12.50	8.33	10	10	8
Ponds + fastanks + concrete tanks	10	12.50	16.66	20	10	14
Number of production cycles /year						
[1-3]	20.51	10.25	28.21	20.51	20.51	78
]3-12]	18.18	36.36	9.09	18.18	18.18	22

n: Number of farms per Division; N: Total number of audited farms; 1: relatively high number of fish fed both naturally and with industrial feed; 2: a single fish species is farmed; 3: several fish species are farmed together in the same culture facility; 4: fish are reared together with other animals like fowls or pigs (pigs dung from piggeries fertilize water)

Adoption Rate of Biosecurity Measures

The overall adoption rate of biosecurity measures (Table 3) was intermediate, i.e., 41±29.12% of farms adopted at least one biosecurity measure. The adoption rate varied non-significantly (F= 1.12; p = 0.350) from 36.46±27.45% (Mefou-and-Afamba, Mfoundi) to 44.17±33.61% (Nyong-and-So'o). Irrespective of Divisions, the most adopted measures were "sanitary lock" implemented by 88% of farms and "No exchange of breeding tools between farms " practiced by 94% of farms, while the least adopted measures were "veterinary intervention" carried out by 4% of farms, "incineration of dead fish" and "special outfit for visitors" not applied in any (0%) of the inspected farms. Measures such as "water quality analysis" and "use of foot baths"

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were not adopted in the Lekie Division, while in Nyong-and-So'o no farm adopted the measures" captured fish not put back into the water " and "water quality analysis".

Adoption Rate of Biosecurity Components Based on Farms' Location

The biosecurity adoption rate based on farms' location (Table 4) showed an overall intermediate value of 41±29.12% with no significant variation (F= 1.12; p = 0.350) between Divisions. The traffic control component was the most adopted (p > 0.05) followed by isolation and sanitation.

Table 3. Adoption rate (%) of biosecurity measures in the Centre Region, Cameroon.

N°	Biosecurity measures and components	Divisions					Overall (N=50)
		Lekie (n=10)	Mfoundi (n=8)	Mefou-and-Afamba (n=12)	Mefou-and-Akono (n=10)	Nyong-and-So'o (n=10)	
	Biosecurity component related to isolation						
1	Farm is fenced	80	87.50	41.66	50	70	64
2	Other animals species are absent on the farm	30	25	16.66	20	30	24
3	New fish are quarantined before rearing	30	62.50	16.66	50	40	38
4	Absence of bushes and trees around farms	30	37.50	25	30	60	36
5	Space for visitors	20	25	8.33	40	20	22
6	Water flow is continuous	80	75	83.33	50	10	78
7	Rearing facilities are layout in derivation	80	75	75	80	80	78
	Biosecurity component related to traffic control						
8	Visitors not allowed to have contact with water	50	87.50	75	8	90	76
9	No exchange of breeding tools between farms	100	87.50	83.33	10	100	94
10	Water supply tracks protected to trap debris and unwanted aquatic animals	30	25	25	20	80	36
	Biosecurity component related to sanitation						
11	Use of footbaths	0	12.50	25	10	10	12
12	Veterinary intervention	0	0	16.66	0	0	4
13	Incineration of dead fish	0	0	0	0	0	0
14	Special outfit for staff	30	12.40	16.66	20	50	26
15	Special outfit for visitors	0	0	0	0	0	0
16	Analysis of water quality	0	25	25	10	0	12
17	Diagnosis of fish diseases	40	25	25	30	20	28
18	Sanitary lock	90	87.50	91.66	80	90	88
19	Awareness of biosecurity measures	30	12.50	16.66	10	60	26
20	Awareness of fish diseases	80	87.50	50	80	70	72
21	Disinfection of breeding tools before use	40	62.50	41.66	30	60	46
22	Disinfection of breeding tools after use	20	62.50	25	30	60	38
23	Treatment of fish diseases	70	87.50	58.33	70	60	68
24	Captured fish not put back into water	20	25	33.33	10	0	18

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Overall (mean ± standard deviation)	39.58±31.83	36.46±27.45	36.46±27.45	37.50±30.25	44.17±33.61	41.00±29.12

n: Number of farms per Division; N: Total number of audited farms.

Table 4. Adoption rate (%) of biosecurity components to the location of the farms in the Centre Region of Cameroon.

Biosecurity Components	Administrative Divisions of fish farms					Overall (N=50)	F	p
	Lekie (n=10)	Mfoundi (n=8)	Mefou-and-Afamba (n=12)	Mefou-and-Akono (n=10)	Nyong-and-So'o (n=10)			
Isolation	50 ± 28.28 (20-80)	38.09±29.99 (8.33–83.33)	38.09±29.99 (8.33- 83.33)	45.71±19.02 (20-80)	57.14±28.70 (20-100)	48.57±24.32 (22-78)	0.61	0.657
Traffic control	60±36.06 (30-100)	61.11±31.55 (25- 83.33)	61.11±31.55 (25 - 83.33)	66.67±41.63 (20- 100)	60±43.59 (10-90)	68.67±29.69 (36 -94)	0.02	0.910
Sanitation	30±31.13 (0- 90)	30.35±24.15 (0 - 91.66)	30.35±24.15 (0 – 91.66)	27.14±28.94 (0-100)	34.29±32.75 (0- 90)	31.29±27.97 (0- 88)	0.11	0.978
Overall	39.58±31.83 (0-100)	36.46±27.45 (0-91.66)	36.46±27.45 (0-91.66)	37.50±30.25 (0-100)	44.17±33.61 (0-100)	41±29.12 (0-94)	1.12	0.350
F	1.73	1.66	1.66	2.88	1.53	2.73	-	-
p	0.201	0.215	0.215	0.079	0.241	0.089	-	-

Mean ± standard deviation (minimum-maximum); n: Number of farms per Division; N: Total number of audited farms

Overall Compliance Rate of Biosecurity Measures

Overall, the compliance rate of biosecurity measures (Figure 2) was intermediate (40.98±15.20%) and ranged insignificantly (K= 4.23; p = 0.376) from 36.46± 17.67% (Mefou-and-Afamba) to 47.92± 15.37 % (Nyong-and-So'o).

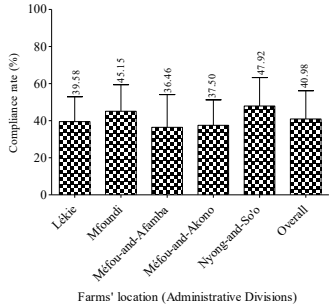

Figure 2. Overall compliance rate of biosecurity measures in the Centre Region of Cameroon.

Farms Frequency Distribution According to the Compliance Rate of Biosecurity Components and Farms Location

Globally, biosecurity practices were not good (Table 5). Overall, 76% and 24 % of farms had respectively an intermediate and low compliance rate. Whatever the Division, the proportion of farms with an intermediate compliance rate was the highest, ranging from 58.33% (Mefou-and-Afamba) to 100% (Mfoundi). Fish farmers were more likely to observe the traffic control component, with 34% of farms with an intermediate compliance rate (68.66± 26.44%), followed by the isolation (48.57± 21.60%) and sanitation (31.28±14.35%) components observed by 78; 76 and 66% of farms respectively. Regardless of the farm's

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geographical location and biosecurity component, nearly 73% of farms were at moderate risk of contamination by pathogens. Regarding sanitation, no farms (0%) recorded a good biosecurity practice.

Table 5. Farms frequency distribution (%) according to the compliance rate (%) of biosecurity components in the Divisions of the Centre Region of Cameroon.

CR (%)	Administrative Divisions					Overall (N= 50)
	Lekie (n =10)	Mfoundi (n =8)	Mefou-and-Afamba (n =12)	Mefou-and-Akono (n =10)	Nyong-and-So'o (n =10)	
	%	%	%	%	%	%
Isolation						
[0-25]	20	0	16.66	20	10	14
]25-75]	60	87.50	83.33	80	80	78
]75-100]	20	12.50	0	0	10	8
Traffic control						
[0-25]	0	0	0	0	0	0
]25-75]	80	75	75	80	20	66
]75-100]	20	25	25	20	80	34
Sanitation						
[0-25]	40	25	50	50	30	24
]25-75]	60	75	50	50	70	76
]75-100]	0	0	0	0	0	0
Overall						
[0-25]	20	0	41.66	30	10	24
]25-75]	80	100	58.33	70	90	76
]75-100]	0	0	0	0	0	0

CR: Compliance rate; n: Number of farms per Division; N: Total number of audited farms

Distribution of the Compliance Rate Based on the Zootechnical Characteristics of Farms

Concerning the zootechnical characteristics of farms (Table 6), biosecurity measures were significantly more observed in intensive, nursery farms and those whose culture facilities were fastanks + concrete tanks with 3 to 12 production cycles per year.

Table 6. Distribution of the compliance rate (%)to the zootechnical characteristics of fish farms in the Centre Region of Cameroon.

zootechnical characteristics	Modalities	Compliance rate of biosecurity measures	F	p
Production systems	Intensive	57.50^{a}± 9.78 (37.50 -66.66)	15.40	0.001*
	Semi-intensive	39.14^{b}±12.69 (20.83 - 62.50)		
	Extensive	21.87^{c}±5.24 (16.66 -29.16)		
Type of culture	Monoculture	45.79^{a}±15.00 (20.83 - 66.66)	3.19	0.584
	Polyculture	34.93^{a}±14.87 (16.66 - 62.50)		
	Monoculture + polyculture	43.33^{a}±9.59 (29.16 - 54.16)		
Culture phases	Nursery	56.94^{a}±10.48 (45.83 -66.66)	10.05	0.001*
	Growout	34.89^{b}±13.25 (16.66 -62.50)		
	Nursery + growout	50.78^{c}±12.72 (21.00- 66.66)		
Culture facilities	Ponds	30.63^{a}±13.34 (16.66 -62.50)	4.19	0.01*
	Fastanks	48.80^{b}±14.38 (29.16 – 66.66)		
	Concrete tanks	44.44^{a}±18.79 (25.00 -62.50)		

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	Ponds + fastanks	46.87[a]±10.39 (33.33 -62.50)		
	Ponds + concrete tanks	32.50[a]±6.85 (25.00 -41.66)		
	Fastanks + concrete tanks	56.00[b]±7.70 (44.83-62.50)		
	Ponds + fastanks + concrete tanks	48.64[a]±15.68 (21.00 -62.50)		
Number of production cycles /year	[1-3]	38.14[a]±15.31 (16.66 - 66.66)	U=107.5	0.01*
	]3-12]	51.04[b]±9.93 (33.33 - 66.66)		

Mean ± standard deviation (minimum-maximum); *: Significant; a,b,c: Values with different letters are significantly different ($p < 0.05$); p: Error probability; U: Mann-Whitney test value; F: Analysis of Variance value

Relationship Between Fish Farms Characteristics and Compliance Rate of Biosecurity Measures

The relationship between zootechnical characteristics and biosecurity compliance rate (Table 7) showed that protection from wild animals, quarantine of new fish, and the number of production cycles per year strongly, positively, and significantly affected the biosecurity compliance rate in the farms. The linear regression model (Figure 3) between the compliance rate (y) and the number of production cycles per year (x) was given by the equation $y = 4.65x - 0.04176$.

Table 7. Multivariate linear regression analysis of the zootechnical characteristics and the observance of the biosecurity measures in the Centre Region of Cameroon.

Zootechnical characteristics	Regression coefficient	p	R^2	Constant
Production systems	5.661	0.106		
Types of culture	0.250	0.867		
Culture phases	-2.969	0.114	MR^2=0.672	
Reared species	-3.207	0.089		33.266
Protection against wild animals	12.311	0.012*	AR^2=0.539	
Man power	1.045	0.435		
Feeding frequency	-0.565	0.578		
Number of production cycles per year	13.787	0.030*		
Water source	2.333	0.638		
Types of culture facilities	1.105	0.328	MR^2=0.832	18.786
Culture facilities' sizes	-0.001	0.293	AR^2= 0.658	
Number of culture facilities	0.084	0.799		
Quarantine of new fish	10.383	0.011*		
Treatment of water before use	10.129	0.235		
Acclimatization of new fish	-2.946	0.254	MR^2=0.809	54.750
Type of feeds	5.465	0.638	AR^2=0.449	
Duration of feed storage	-0.135	0.910		

MR^2 : Multiple R-squared; AR^2 : Adjusted R-squared; R^2: Determination coefficient ; p: Error probability; * : Significant

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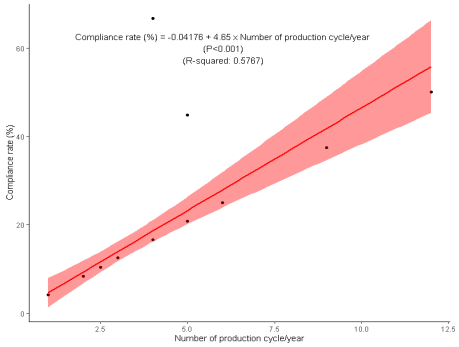

Figure 3. Linear regression model between the compliance rate of biosecurity measures and the number of production cycles per year.

Biosecurity Measures Affinities and Interactions Between Fish Farms

The biosecurity affinities and interactions between fish farms in the Divisions illustrated in Figure 4 showed that the first two axes of the Principal Component Analysis (PCA) explained 81.3% of the variance in the data. Axis 1 (PCA_1) expressing 53.5% of the total variance highlighted three groups of relationship between Divisions and biosecurity components after projection. The first group was made up of farms in the Mfoundi and Mefou-and-Afamba Divisions, which provided no relevant information on biosecurity practice. The second group, comprising farms in Nyong-and-So'o and Lekie, showed an affinity for traffic control and isolation. The farms in the Mefou-and-Akono Divisions that made up the third group showed more affinity for sanitation.

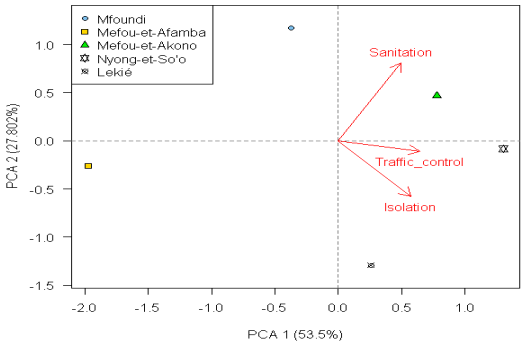

Figure 4. Illustration of the principal component analysis of biosecurity affinities between farms of the Divisions of Cameroon's Centre Region.

The results obtained on the effect of zootechnical factors on biosecurity practices on fish farms in the Centre Region of Cameroon showed that *C. gariepinus* was the most reared species. This was due to the species' hardiness, rapid growth, reproductive control, and high consumption by the local population (MINEPIA, 2014). Ngueguim *et al.* (2020), on the other hand, reported that Nile tilapia (*O. niloticus*) was the predominant farmed species in the western region of Cameroon (52.9% of fish farmers) due to its easy production technique, disease resistance, and availability from the extension service (MINEPIA, 2014).

This variation in the choice of rearing species according to geographical zone could be explained by climate variations and dietary habits dependent on local sociology. The semi-intensive system was the most widely used (74% of farms), due on the one hand to the evolution and improvement of fish farming production techniques, and on the other hand to the practice of fish farming as a secondary activity by promoters and the predominant type of infrastructure (72% of pond farms) in the study area.

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Indeed, the present study reported that only 16% of promoters practiced fish farming as their main activity

This result differs from Ngueguim *et al*. (2020) and Wanja *et al*. (2020), who showed that the most widely used production system was extensive in West Cameroon and Central Kenya respectively. The reason could be the lack of mastery of production techniques, the high cost, and even the scarcity of quality feed in the local market. The production system varies according to geographical zone, due to variations in production techniques.

Non-integrated fish farming and the ground-based farming system were the most widely practiced, probably because of the exploitable land surface. This study reported that 70% of farms were built on an area greater than 500m². These observations corroborate those made by Tiogué *et al.* (2020) in the Mbam and Inoubou Administrative Division (Cameroon) in which the lack of experience, technical skills, and financial support of some Cameroonian fish farmers was at the origin of these farming practices. The monoculture has been predominant because fish farmers lack knowledge of farming techniques since only 44% have received training in fish farming. This observation is contrary to those reported by Tiogué *et al*. (2020) and Omitoyin and Osakuade (2021) who noted that polyculture was the most practiced in Mbam and Inoubou Division and Nigeria, due to the need for diversification, management of cannibalism in production ponds or maximum utilization of feed.

As for annual productivity, around 70% of farms recorded a low value (0-20 kg/m^3/year). This could be explained by the semi-intensive farming system and the heavy use of ponds. Productivity in semi-intensive ground-based systems cannot be maximized, as water characteristics are difficult to control.

The maximum number of farms (44%) audited recorded a fish mortality rate ranging from 15% to 30% of production. These mortalities might be caused by infectious diseases due to ignorance (18%) of biosecurity practices by fish farmers, negligence (28%), and the relatively high cost of biosecurity reported by 48% of producers. This mortality rate is lower than that reported by Obosi and Agbeja (2015), i.e., 25 to 75% in 71.25% of farms in Nigeria, due to the gradual improvement in farming techniques in Cameroon. Indeed, the latter authors identified low production technicality as the main cause of fish mortalities in the majority (63%) of farms in Nigeria.

The overall intermediate adoption rate (41±29.12%) recorded by the present study was reported (40.40±30.10%) by Fonkwa et *al*. (2023a and b) in fish farms in the Wouri Division, Littoral Region-Cameroon. The cause would be the high cost of implementing biosecurity measures (Fonkwa *et al*., 2023a and b; Bera *et al.*, 2018), and the lack of fish farming training. Kouam and Moussala (2018), Kone (2015), and Ngueguim *et al.* (2020) have noted that the high adoption rate is due to fear of production losses caused by diseases. This has led fish farmers to be receptive to veterinary advice and recommendations, and to adopt the least onerous and easily applicable biosecurity measures.

When comparing the adoption rate between Divisions, it appears that values varied slightly between 36.46±27.45% (Mefou-and-Afamba, Mfoudi) and 44.17 ± 33.61% (Nyong-and-So'o), probably due to variations in socio-demographic and technico-economic characteristics. The most adopted biosecurity component was traffic control, followed by isolation and sanitation. This ranking concurs with that of Ngueguim *et al*. (2020), Kone (2015), and Kouam and Moussala (2018). This observation can be explained by the lower cost of implementing measures in the traffic control component, and its smaller number of measures (3) compared with the isolation and sanitation components made up of 7 and 14 biosecurity measures respectively.
Regardless of Divisions, the most adopted measures were "sanitary lock" and "no exchange of materials with other farms", while

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the least adopted was "veterinary intervention", "dead fish incinerated" and "special outfit for visitors". The latter measures are the most important to improve. The most widely adopted measures would be less technically and financially demanding (Bera *et al*., 2018; Ricou, 2006). The low adoption rate of the "special outfit for visitors" measure is very risky, as humans can act as mechanical vectors of disease for fish (Kouam *et al.,* 2019). The non-adoption of the "use of foot baths" measure by farms in the Lekie Division is problematic and contrary to the recommendations of Craig *et al*. (2006) and Brister and Wimmer (2010) that foot baths should be used to disinfect rolling objects and then Kone (2015) who advocates their use to disinfect outsiders visiting farms. Socio-demographic and economic similarities are suspected to be the root of the non-significant variation in the adoption rate of biosecurity measures between the Divisions of the Centre Region of Cameroon.

The overall compliance rate of biosecurity measures in the Centre Region was intermediate (40.98± 15.20%) and comparable to that (40.52±14.70%) recorded by Fonkwa *et al.* (2023a and b) in fish farms in the Wouri Division, Cameroon. In other words, the farms were at moderate risk of pathogen contamination. Optimal fish farming performance requires good biosecurity practices. This intermediate compliance rate is thought to be due to a lack of knowledge, financial constraints (Obosi and Agbeja, 2015; Bera *et al.,* 2018), and ignorance (Ricou, 2006). Indeed, this audit revealed that only 44% of fish farmers had received training in fish farming around 48% mentioned the problem of the high cost of implementing biosecurity measures and 28% were unaware of good biosecurity measures practices. Fish farmers did not understand that good biosecurity practices help reduce financial losses due to infections (Racicot and Vaillancourt, 2009). It also helps meet customer and consumer demand for healthy, pathogen-free products. Good biosecurity practices are a step towards farm certification, thus guaranteeing better fish and customer health.

This intermediate compliance rate could explain the mortality rates of sometimes up to 100% observed on farms and especially hatcheries in Cameroon. The compliance rate obtained is higher than the low value (0-25%) recorded by Ngueguim *et al.* (2020) in fish farms in the West Region of Cameroon. The same observation was made by Kone (2015) in Ivory Coast. Ignorance, negligence, and inappropriate application of biosecurity measures by fish farmers would explain why the said farms were at major risk of pathologies. The public authorities should strengthen fish farmers' biosecurity skills through training seminars, and step up funding for fish farming projects. Compliance rates varied without significant difference between Divisions, probably due to comparable socio-demographic and technico-economic characteristics.

The frequency distribution of farms according to compliance rate and geographical location showed that, overall, biosecurity practices on farms were not good. Overall, 78% of farms had an intermediate compliance rate (moderate risk level), compared with 22% with a low compliance rate (major risk of contamination level). The norm would be that 100% of farms should be at minor risk of contamination. These results are justified by the fact that most fish farmers (56%) are not trained in fish farming and are faced with financial constraints (48% of fish farmers). Ricou (2006) and Boutin (2001) have associated low compliance rates with farmer ignorance and inappropriate application of biosecurity measures. According to Obosi and Agbeja (2015) and Bera *et al.* (2018), low compliance rates are linked to a lack of knowledge, the absence of a biosecurity audit program, and financial constraints. Fish farmers need to be trained or retrained during their farming activity. They can also form cooperatives to help each other.

Fish farmers were more likely to observe measures relating to the traffic control component, followed by isolation and

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sanitation. This trend was reported by Ngueguim *et al.* (2020) and Kouam *et al.* (2019). The rationale behind this is the low cost of implementing the traffic control component and its lower number of measures (3 measures) compared with the isolation and sanitation components, consisting of 7 and 14 biosecurity measures respectively. Concerning the sanitation component, no farms (0%) observed good biosecurity practices. This could lead to up to 100% of production and financial losses on the farm. This result is comparable to that obtained by Kone (2015) in fish farms in the Ivory Coast and Ngueguim *et al.* (2020) in the West Region of Cameroon. Probably, no producer in the Central Region would invest enough money in biosecurity practices or be better trained in fish farming.

The multivariate linear regression analysis of technical factors affecting biosecurity implementation in the Centre Region showed that protection against wild animals, quarantine of new fish, and the number of production cycles per year strongly, positively, and significantly affected the compliance rate of biosecurity measures. The strong, positive, and significant relationship between protection from wild animals and compliance rate can be explained by the fact that wild animals are vectors of pathogens. This result differs from that of Ngueguim *et al.* (2020) highlighted a weak, positive, and non-significant relationship between protection from wild animals and the rate of compliance with biosecurity measures. This difference may be due to variations in the audited farm sample sizes. Quarantining new fish would prevent the occurrence and spread of pathologies on farms. The number of production cycles per year significantly affected the compliance rate because an increase in the number of production cycles increases the number of tasks and the neglect of biosecurity practices, especially if the workforce is small. Infectious pathologies are increasingly becoming a major constraint in fish farming production due to non-compliance with hygiene or biosecurity measures.

The principal component analysis of the relationship between farms in the Divisions of the Centre Region of Cameroon and biosecurity practices revealed affinities and dissimilarities between certain farms reflect a socio-demographic proximity or affinity (Fonkwa *et al*., 2023a).

The issue of compliance with biosecurity measures on farms is undeniable because good practice will allow the health certification of farms and will therefore ensure the sanitary quality of fish and customers. This study will certainly help stakeholders in the aquaculture sector in the Centre Region of Cameroon and other countries with comparable farming systems to improve the level of biosecurity practices in farms. This will reduce epizootics and optimize production. The biosecurity measures to improve our "veterinary intervention", "dead fish incinerated" and "special outfit for visitors".

CONCLUSION

The investigation of the biosecurity practices in fish farms in the Centre Region of Cameroon revealed an intermediate implementation level. The compliance rate of the biosecurity measures was significantly influenced by the production system, the culture phases and facilities, and the number of production cycles per year. A significant and positive relationship was established between the protection of farms against wild animals, the quarantine of new fish, the number of production cycles per year, and the biosecurity compliance rate. The stakeholders should seriously handle the issue of biosecurity in the fish farming sector to minimize the production loss due to diseases.

CONFLICT OF INTEREST

The authors have no conflict of interest declared.

AUTHOR CONTRIBUTION

Fonkwa Georges conceived the study, was involved in the study design, coordinated the data collection and

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processing, and wrote the first draft that was reviewed and corrected by Kpoumie Nsangou Amidou and Makombu Judith Georgette. Kametieu Djamou Franck Junior collected the data and participated in the manuscript preparation. Tomedi Eyango Minette and Tchoumboue supervised the study. All authors have read and approved the manuscript.

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