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Key risk factors, farming practices and economic losses associated with tilapia mortality in Egypt

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ABSTRACT

Egypt is the topmost aquaculture producer in Africa and the third largest tilapia producer globally. Nile tilapia in particular is the cornerstone of fish farming in Egypt. Recently, fish farms have experienced unusual tilapia mortality during summer season, threatening further growth of the sector. In order to understand risk factors, a questionnaire based cross-sectional study was conducted using tilapia epidemiology and health economics online survey tools. We surveyed 113 tilapia farms in four of the largest tilapia producer governorates (Kafr El Sheikh, Beheira, Sharqia, Faiyum) and one governorate with less farming activity (Minya). Farming practices, biosecurity measures and estimated losses were also assessed. Results indicate that a combination of risk factors contributed to the observed mortality events. We observed significant correlation between water source (surface and irrigation canals) and both occurrence and level of unusual mortality events ($p < .001$). Similarly, higher average water temperature, salinity, and polyculture of tilapia with wild sourced mullet favored the occurrence of unusual mortality ($p < .001$). Unusual mortality level was higher with low inclusion of tilapia in polyculture settings compared to other species ($p = .014$). Average fish weight at mortality peaks also contributed to mortality level ($p = .029$). Farming practices that affected mortality incidences included sharing of equipment between farms ($p < .001$). The overall losses from unusual mortality were estimated at about 11,304,400 EGP (around 720,000 USD). Results of this study indicate further studies are needed to understand better the interactions between necessary pathogens and component (risk factors) causes for tilapia mortalities in Egypt.

1. Introduction

Aquaculture is the fastest growing food production sector in the world with great potential to meet the growing needs for animal protein (Soliman and Yacout, 2016). Egypt is the top aquaculture producer in Africa accounting for two-thirds of the continent's production and the third largest tilapia producer globally after China and Indonesia. Since 2000, there has been a tremendous increase in fish production, which is mainly attributed to the shift from extensive and semi-intensive towards intensive aquaculture systems (FAO, 2010). Therefore, Egyptian aquaculture sector plays a central role in the country's economy, producing over 1.8 million tons of fish including tilapia, mullet and carp in 2017. Additionally, the aquaculture industry provides about 78% of the total national fish production. Furthermore, it secures > 580,000 jobs for workers in this sector (El-Sayed et al., 2015; FAO, 2016a, 2016b; GAFRD, 2014; Mur, 2014; Shaalan et al., 2018). With intensification and increase in aquaculture production, incidences of fish diseases have also increased.

Globally, fish diseases are among the major challenging factors that limit aquaculture productivity and sustainability with subsequent impact on food safety, food security, job stability, and human health. Of all cultivated fish species in Egypt, Nile tilapia in particular is the cornerstone of fish farming. Recently, fish farms have experienced unusual tilapia mortality during summer season. Epidemiological surveys done in 2015 indicated that 37% of fish farms in the three most important Egyptian aquaculture governorates namely Kafr El Sheikh, Beheira and Sharqia were affected with summer mortality syndrome with an average mortality rate of 9.2% and a potential economic impact of around US$100 million (Fathi et al., 2017). Although a multifactorial aetiology is suspected, the actual causes of mortality remain unclear.

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Available studies are limited to disease diagnosis or factors strengthening fish immunity against specific pathogens (Abdel-Razek et al., 2019; Elgendy et al., 2016; Neamat-Allah et al., 2019; Nicholson et al., 2017). Until now, no study has been done on key risk factors and potential economic losses associated with the disease outbreaks. In the present study, we conducted a tilapia epidemiology and health economics survey in five Egyptian aquaculture governorates for the mapping of major risk factors and economic impacts associated with tilapia mortality during summer 2018.

2. Materials and methods

2.1. Study area and farm selection

To investigate the unusual tilapia mortalities, a questionnaire-based survey was conducted in four of the main tilapia-farming governorates including Kafr El Sheikh, Beheira, Sharqia and Faiyum. Additionally, another governorate (Minya) with less farming activity and fewer mortality cases was included. The geographical distribution of the farms (governorate location) used in this study is shown in Fig. 1. The individual farm selection was based on ease of access and farmer willingness to take the interview and provide information on the questionnaire. In total 113 individual fish farms were investigated.

2.2. Questionnaire design

The questionnaire was designed to cover a range of topics presented in Table 1.

Trained data enumerators undertook data collection for the tilapia epidemiology and health economics survey questionnaire through face-to-face interviews with farmers using the mobile data collection tool, Open Data Kit (ODK) collect application of the Kobo toolbox platform.

Fig. 1. Locations of the five surveyed governorates, namely Beheira, Kafr El Sheikh, Sharqia, Faiyum, and Minya. (Source: Google map).

Table 1
Questionnaire design.

Topics	Details
Farmer factors	Gender, age, education level, major occupation and years of aquaculture experience
Farming system	Number and size of ponds, pond type and stocking time
Water management practices	Source, exchange rate, quality parameters under normal conditions before the occurrence of unusual mortality
Stocking information	Species/strain, sex, source of seeds, delivery method, culture type (monoculture or polyculture), stocking frequency per production cycle or year, stocking date, total number and average size of stocked tilapia, cost per seed and average stocking density)
Feed and fertilizers	Feed and fertilizer use, type, brand, quantity, cost, feed conversion ratio
Farm biosecurity level	Number of times fish were introduced after main stocking, biosecurity practices between production cycles, fallow period, shared equipment or staff between farms, daily internal biosecurity measures, frequency of removal and disposal method of dead fish, if they consulted a veterinarian, applied disinfectants or vaccinated fish for the following production cycle.
Mortality data	Occurrence and nature of unusual mortality (mortality level that farmers haven't experienced before and exceeding their expectation), water quality parameters under unusual mortality events based on area not per pond, such parameters include (average of dissolved oxygen (mg/L), temperature (°C), ammonia (mg/L), pH and salinity Mortality onset, number of affected ponds, affected tilapia stock, nature and duration of the mortality event, total mortality percentage, variation in mortality between affected ponds. Average weight of affected tilapia, relevant stressors recalled by the farmers before mortality onset and prominent clinical signs
Economics and economic impact data	Data on total production, losses valuation and cost to produce one Kg of tilapia. Other relevant costs on biosecurity, health screening, chemotherapeutic uses, veterinarian intervention and dead fish disposal

Data collection was conducted offline into mobile phone/tablet allowing completion of multiple surveys without the need of an internet connection. Data were uploaded at internet connection points allowing for revisions of the data by enumerators at convenient times before submitting surveys to online databases. Raw data were exported as a CSV file.

2.3. Data analysis

Prior to analyses, data were checked for quality and re-grouped where possible to make biologically meaningful groups and avoid small groups in categorical data (< 10 entries).

Where variation in the data was present, biologically plausible potential risk factors were explored. Differences in characteristics between farms reporting unusual mortality in the previous year and those reporting no unusual mortality (yes/no, binomial variable) was evaluated by the use of chi-square tests and Mann-Whitney *U* tests, while Kruskal Wallis tests were used to assess factors associated with reported mortality level (%, continuous variable). A p-value $< .05$ was considered statistically significant.

In order to assess the influence of confounding factors on the observed differences in reporting of unusual mortality and the reported mortality levels, we used regression analyses with a logistic regression and generalized linear models respectively. Based on the initial data assessment for variation, association and biological plausibility, the following characteristics were considered potential confounding factors: farming location (north/south), water source, average water temperature, average water salinity, culture type (monoculture/polyculture), average tilapia stocking percentage, average pond size, shared equipment practices and average fish weight at mortality (mortality level only).

Confounding factors with a p-value $< .2$ in the univariable analyses were included in the multivariable regression, where a backward selection followed by a forward selection was used and a p-value $< .05$ was considered statistically significant. Akaike's information criterion (AIC) was used for final model selection (the smaller the value, the better the model) (Burnham and Anderson, 2002) and residuals were plotted to assess model fit. Potential confounding factors were checked for correlation before inclusion in the multivariable regression.

All analyses were performed in R, version 3.5.1 (R Core Team, 2018).

3. Results

All farms with unreliable or incomplete data were excluded. The remaining 113 farms had adequate data quality and were included in the main analyses.

3.1. Farmer and production system characteristics

The farms employed a median of two full-time male staff, ranging from one to six, and a median of two part-time male staff, ranging from zero to seven. No female staff, either full-time or part-time, were employed by the farms. All the farmers in the survey were male, with an average age of 42.5 years (range 25 to 65 years). Those interviewed included: people who were both the farm owner and the farm manager (92.9%), farm managers only (6.2%) and farm owners only (0.9%) indicating that management by owner is common. The vast majority (96.5%) reported being the primary decision maker on the farm, and all but one (99.1%) worked full time on the farm (data not shown).

The majority of farmers (71.7%) had primary school education, 10.6% had some primary or no education and 17.7% had secondary education or higher. No relationship was found between farmer education level and the occurrence of unusual fish mortality ($p = .250$) or the level of observed mortality ($p = .154$) (Table 2). Overall, the experience by tilapia farmers ranged from 0 to 36 years (mean 16.8 years, median 17.0 years) (data not shown) among respondents, with Minya farmers having the least farming experience (maximum one year) (Table 3).

All farms practiced an all-in, all-out system. 89.4% of the farms were a mixture of commercial and homestead farms while 10.6% of the farms were exclusively commercial. Commercial farms were represented in all governorates (Table 3). All the investigated farms in the four top producing governorates (Beheira, Kafr El Sheikh, Sharqia and Faiyum), used earthen ponds. The farms in Minya differed from the farms in other governorates by using concrete ponds (37.5%) or plastic-lined sand ponds (62.5%). Average pond size was 3.2 acres (range 0.2 to 15.0 acres). Larger pond size was significantly associated with the occurrence of unusual mortality ($p < .001$, Table 2).

Tilapia only (monoculture) represented 20.4% of the farms, while the rest of the farms stocked tilapia with other fish species (polyculture) (Table 2). Minya was the only area having tilapia monoculture only, while Sharqia had polyculture only (Table 3). The average percentage of tilapia in polyculture system was 91.2% (Table 2). Culture type (polyculture) and average percentage of tilapia (low tilapia percentage in polyculture) were significantly associated with the occurrence of unusual mortality ($p < .001$, Table 2).

The geographical distribution of farms by governorate locations is shown in Fig. 1 and in Table 2. Due to similarities in overall features, governorates were grouped into northern or southern locations. Governorate group was significantly associated with the occurrence of unusual mortality ($p < .001$) and mortality level ($p = .026$) (Table 2).

Table 2
Factors assessed for association with unusual mortality occurrence and mortality level.

	All farms	Reported unusual mortality (no/yes)			Reported unusual mortality level (%)	
	N = 113	No (N = 24)	Yes (N = 89)	p	N = 89	
Variable	n (%) or mean (min, max)	n (%) or mean (95% CI)			mean (95%CI)	p
Farmer education				0.250		
Missing, none or some primary	12 (10.6)	2 (8.3)	10 (11.2)		30.3 (21.0-39.6)	0.154
Primary	81 (71.7)	15 (62.5)	66 (74.2)		24.7 (21.8-27.6)	
Secondary and above	20 (17.7)	7 (29.2)	13 (14.6)		23.6 (13.7–33.5)	
Governorate group				**< 0.001**		**0.026**
Southern (Faiyum & Minya)	25 (22.1)	22 (91.7)	3 (3.4)		9.0 (−14.7–32.7)	
Northern (Beheira, Kafr El Sheikh & Sharqia)	88 (77.9)	2 (2.3)	86 (96.6)		25.7 (23.1–28.4)	
Water source				**< 0.001**		**< 0.001**
Mixed source	28 (24.8)	2 (8.3)	26 (29.2)		21.0 (15.5–26.5)	
Borehole water or lake	24 (21.2)	21 (87.5)	3 (3.4)		7.3 (0.0–23.9)	
Irrigation canal or river	61 (54.0)	1 (4.2)	60 (67.4)		27.9 (25.0–30.7)	
Culture type				**< 0.001**		0.402
Monoculture	23 (20.4)	14 (58.3)	9 (10.1)		21.7 (15.3–28.0)	
Polyculture	90 (79.6)	10 (41.7)	80 (89.9)			
Average percentage tilapia stocked	91.2 (70.0–97.0)	96.2 (95.5–96.9)	90.6 (89.7–91.4)	**< 0.001**		
Average pond size (acres)	3.2 (0.2–15.0)	1.5 (0.1–3.0)	3.6 (0.3–15.0)	**< 0.001**		
Average stocking density (tilapia/m^3)	4.3 (2.0–18.0)	5.6 (3.8–7.4)	4.0 (3.6–4.3)	0.421		
Equipment sharing				**< 0.001**		0.804
None	80 (70.8)	24 (100)	56 (62.9)		25.6 (22.2–25.6)	
With 1 farm	21 (18.6)	0	21 (23.6)		25.2 (12.2–31.1)	
With 2 or more farms	12 (10.6)	0	12 (13.5)		23.3 (15.9–30.8)	
Average water temperature	30.2 (27.0–33.0)	28.9 (28.5–29.3)	30.6 (30.3–30.8)	**< 0.001**		
Average water salinity	4.9 (0.0–15.0)	0.7 (0.1–1.2)	6.3 (5.6–7.1)	**< 0.001**		

Bold indicates P-values < 0.05

3.2. Water source and water management practices

For statistical analyses, irrigation canal and surface water sources were combined, as were lake water and borehole water as these water sources were deemed to share similar risk profiles in relation to disease spread. The majority of farms, 54% (n = 61), depended on irrigation canal and surface water as their water source, while about 21% (n = 24) used borehole water or lake water and 25% (n = 28) mixed water sources (Table 2, Fig. 2). Proportions of water sources for fish farming differed among governorates with different governorates using mixed sources, surface or irrigation canals, borehole water, and Faiyum depending solely on lake water (Table 3). About 67% (n = 60) of the farms affected by unusual mortality (n = 89) depended on irrigation canal and surface water as main water source. Water source was significantly associated with the occurrence of unusual mortality ($p < .001$, Table 2).

The exact rate of water exchange varied widely within individual farms and was difficult to determine for all farms (data not shown).

Average water temperature and salinity levels for each governorate are shown in Table 3. Both water temperature and salinity were significantly associated with the occurrence of unusual mortality ($p < .001$), Table 2.

3.3. Stocking information

Nile tilapia (monosex) was the only tilapia species stocked in all the farms. Only 2 farms (1.8%) used their own seed stock with the majority of the rest sourcing seed from hatcheries. Most farmers (68.1%) collected their seed directly from hatcheries, 23.9% got deliveries from middlemen and 8.0% of the seed was delivered by hatcheries/nurseries. Most tilapia seed (94.7%) came from Kafr El Sheikh, with only 3.5% from Sharqia and 1.8% from Faiyum and Damietta (data not shown).

Most ponds were stocked once a year (93.8%), starting from late March, April or May, and only 6.2% of farms stocked their ponds twice a year. While fish were stocked at the same time, harvest was done on multiple occasions, depending on market requirements. Tilapia were either stocked at 1–2 mm “mosquito size” or incubated from previous cycles until they reached 3–5 cm then distributed to grow-out ponds. Stocking density varied according to water quality. Stocking density, mean 4.3 tilapia/m^3 (range 2.0–18.0), was not statistically associated with the occurrence of unusual mortality ($p = .421$) (Table 2). Average stocking density differed per governorate (Table 3 and Fig. 3).

3.4. Feed and fertilizers

All farms used commercial feed, with 15 different brands being represented (data not shown). One farm supplemented with homemade feed. The amount of feed varied with stocking density. Feed conversion ratio (FCR) varied from one area to another; and averaged 1.4. Only 8.8% of farms reported using either organic fertilizers (mainly chicken manure) or a combination of organic and inorganic fertilizer (data not shown).

3.5. Biosecurity practices

Similarly, only 3 (2.7%) of the farms disinfected fish when new stock was brought in and 10.6% kept fish in separate tanks to monitor appearance of any clinical signs following transportation. However, none of the farms reported any kind of vehicle disinfection upon entry. Except for three farms (2.7%), all other farmers did not introduce new fish onto farm after main stocking events. Majority of farmers (33.3%) dried ponds between production cycles. The period for drying ponds differed; never or < 3 weeks (8%), from 3 to 4 weeks (27.4%), 5–10 weeks (42.5%), or longer than 10 weeks (22.1%) (Table 3, Fig. 4). About 25% of farmers combined pond drying with liming and 16.6% with cleaning nets. A total of 16.6% combined drying, liming and net cleaning while 4.6% cleaned nets only without drying or liming, the rest are not practicing any of above mentioned measures (Fig. 5, data not shown). Most of farms without unusual mortality practiced drying alone or combined drying with liming.

Hand disinfection was the most common (98%) biosecurity measure used by service providers at the farm during arrival and departure.

Table 3
Farm and farming practices, culture systems, water sources and levels of unusual mortality in different governorates.

	Governorate (number of farms studied)				
	Beheira (32)	Faiyum (17)	Kafr El Sheikh (50)	Minya (8)	Sharqia (6)
Stocking density (tilapia/m^3)	4.0 (2.0–6.0)	3.4 (2.4–4.4)	3.6 (2.4–5.4)	11.8 (4.5–18.0)	4.3 (3.7–4.9)
Water source and water parameters					
Water source					
Mixed	1 (3.1)	0	24 (48.0)	2 (25.0)	1 (16.7)
Borehole water only	0	0	1 (2.0)	6 (75.0)	0
River or irrigation canal only	31 (96.9)	0	25 (50)	0	5 (83.3)
Lake only	0	17 (100)	0	0	0
Average water temperature baseline	30.3 (29.0–32.0)	29.0 (27.0–30.0)	30.9 (29.0–33.0) (17 farms didn't measure)	28.3 (27.0–29.0)	31.6 (31.0–32) (1 farm didn't measure)
Average water salinity baseline	6.6 (2.0–11.0)	0.06 (0–0.5)	6.5 (1.0–15.0) (17 farms didn't measure)	1.2 (0.5–2.0)	10 (5 of 6 farms didn't measure)
Farmer and production system information					
Years of tilapia farming experience	20.2 (1–36)	14.1 (1 – 22)	18.4 (3 – 33)	0.9 (0–1)	13.8 (11–17)
Pond type					
Other	0	0	0	8 (100)	0
Earthen	32 (100)	17 (100)	50 (100)	0	6 (100)
Culture type					
Monoculture	4 (12.5)	6 (35.3)	5 (10.0)	8 (100)	0
Polyculture	28 (87.5)	11 (64.7)	45 (90.0)	0	6 (100)
Farm type					
Commercial & homestead	31 (96.9)	16 (94.1)	41 (82.0)	8 (100)	5 (83.3)
Commercial only	1 (3.1)	1 (5.9)	9 (18.0)	0	1 (16.7)
Average pond size (acre)	3.8 (1.8–6.0)	1.9 (1.1–3.0)	3.7 (0.8–15.0)	0.3 (0.1–0.6)	2.6 (1.8–3.3)
Pond drying period					
Never or < 3 weeks	0	0	1 (2.0)	8 (100)	0
3–4 weeks	8 (25.0)	4 (23.5)	15 (30.0)	0	4 (66.7)
5–10 weeks	10 (31.2)	13 (76.5)	25 (50.0)	0	0
> 10 weeks	14 (43.6)	0	9 (18.0)	0	2 (33.3)
Equipment sharing					
Non	18 (56.3)	16 (94.1)	33 (66.0)	8 (100)	5 (83.3)
With 1 farm	10 (31.3)	1 (5.9)	9 (18.0)	0	1 (16.7)
With 2 or more farms	4 (12.5)	0	8 (16.0)	0	0
Mortality information					
Baseline mortality level %	3.0 (1 – 10)	0.9 (0–2)	2.5 (0.5–10)	0.3 (0–2)	2.7 (1–5)
Proportion of farms reporting unusual mortality n (%)	32 (100)	2 (12)	48 (96)	1 (13)	6 (100)
Unusual mortality %	32.9 (15.0–65.0)	3.5 (3.0–4.0)	20.1 (5.0–40.0)	20	32.8 (22.0–45.0)
Average weight at mortality event (g)	143 (100 – 200)	285 (170–400)	166 (100–250)	250	167 (100–250)

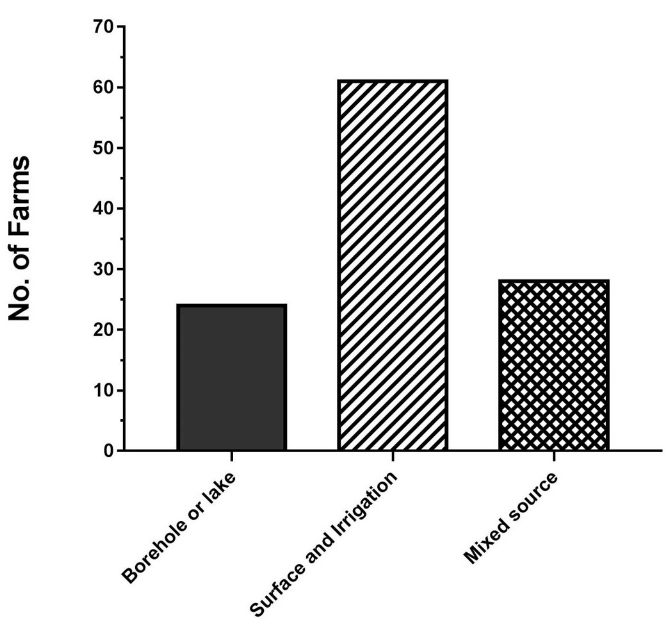

Fig. 2. Water sources used by farms in study area.

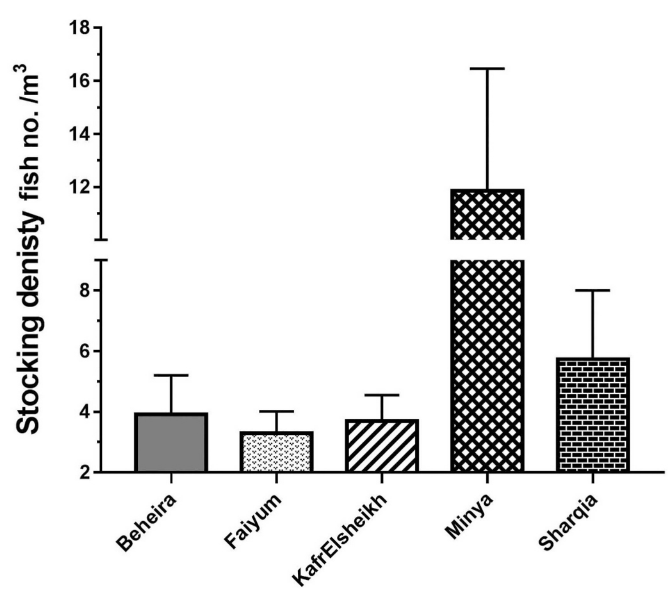

Fig. 3. Average stocking density for all governorates included in this study.

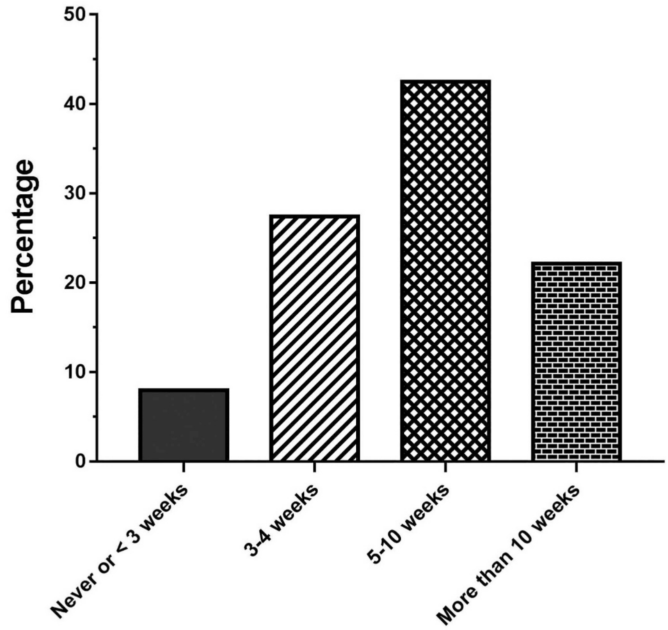

Fig. 4. Number of farms using different drying period between production cycles.

Service providers included feed suppliers, harvesters, in addition to pond excavators and veterinarians. About 95% of farmers reported hand disinfection (washing hands with soap) and the rest reported disinfection of equipment (cleaning) in addition to hand washing (data not shown). Equipment-sharing practices varied between governorates (Table 3), and were significantly associated with the occurrence of unusual mortality ($p < .001$, Table 2). The majority of farms (70.8%) did not share equipment, 18.6% shared equipment with another farm while 10.6% shared with more than two or more farms (Table 2).

3.6. Descriptive analyses of mortality

Although most of farmers were concerned with mortality, no farmer had paper or digital records of mortality events, but depended on memory recall. Reported baseline mortality levels ranged from 0 to 10%, with an average of 2.3%, with baseline mortality levels varying by governorate (Table 3). While the average percentage baseline mortality was small, it was considered to be a cause of economic losses by 63% of farmers (data not shown).

As many as 78.8% of the farms experienced unusual mortality with 96 to 100% of farms in Beheira, Kafr El Sheikh and Sharqia (the northern area) reporting having had unusual mortality events. On the other hand, 12 and 13% of farms reported unusual mortality in Faiyum and Minya (the southern farming area) respectively (Table 3). Overall, the level of unusual mortality by governorate ranged from 3 to 65% (Table 3) with a mean of 25.2% and a median of 22% (data not shown). The highest mean unusual mortality was measured in Beheira (32.9%) and the lowest in Faiyum (3.5%), with significant differences between the two governorates ($p < .001$, data not shown). The level of unusual mortality was also significantly associated with water source ($p < .001$, Table 4).

Those mortalities mainly started during July as reported by 62% of farmers (data not shown), with some reports in late May, June and August by others (38%). All ponds within investigated farms were equally affected in terms of mortality except for 12.3% of farmers who reported variations among ponds. Mortality mainly affected tilapia only and not other species (data not shown). Most farmers (94.4%) reported that mortalities happened gradually. Only 5.6% of farmers reported sudden mortalities. The duration of mortality varied among farms, with 81% for more than a month, 18% within a month and 1% within less than a week.

Among the stress factors that could predispose fish to disease resulting in unusual mortality, 12.4% of farmers assumed it to be related to weather stress (high temperature), 15.7% to water quality and 60.7% to both. In general water parameters data are based on area (where group of farms share same water source) and not per individual pond (as reported by health providers). Water parameters during disease outbreaks compared to normal conditions are summarized in Fig. 6.

Few farmers (3.5%) reported unusual mortality following the change of fish feed provider and the rest reported mortality without any prior stressors. One farmer mentioned pesticides in irrigation water as being the main contributing factor leading to mortality.

3.7. Clinical signs

Red patches on fish abdomen were the most prominent clinical sign reported by 54% of farms affected by unusual mortality (data not shown, Fig. 7). Other clinical signs such as exophthalmia, corneal opacity, skin ulceration, swollen vent, tail and fin erosion were also reported (data not shown). Many respondents (73%) reported seasonal recurrence of similar clinical signs either yearly or at regular/irregular intervals (data not shown).

3.8. Altered biosecurity measures following unusual mortality events

Cessation of feeding and removal of dead carcasses were the most common actions taken by farmers (99%) in response to disease outbreaks. In addition, some farmers increased water flow rate (13%) when pond water quality was low. When incoming water salinity increased or deteriorated, some farmers (7%) stopped water exchange. While 9% of farmers consulted veterinarians before medicating sick fish, 25% of farms used some chemicals and/or disinfectants without prescription. Such chemicals include salt solution, formalin bath,

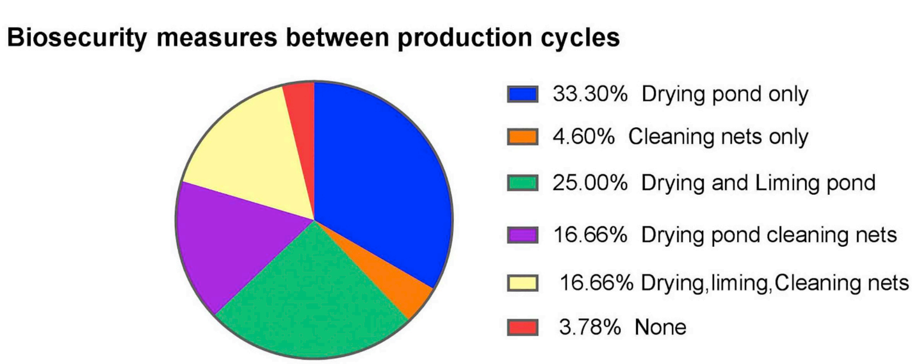

Fig. 5. Percentage of different on-farm biosecurity measures used by farmers between production cycles.

Table 4
Results from the univariable and multivariable regression analyses.

Univariable analysis								
	Occurrence of unusual mortality (no/yes)				Level (%) of unusual mortality			
Variable	OR	95% CI	p	AIC	OR	95% CI	p	AIC
Governorate group				41.4				142.8
Southern (Faiyum& Minya)	1				1			
Northern (Beheira, Kafr El Sheikh & Sharqia)	315	61.6–2766.3	< **0.001**		3.6	2.0–6.8	< **0.001**	
Water source				48.7				130.8
Mixed source	1				1			
Bore water or lake	0.01	0.001–0.059	< **0.001**		0.3	0.2–0.6	< **0.001**	
Irrigation canal or river	4.6	0.4–101.9	0.220		1.5	1.2–1.9	**0.001**	
Average water temperature	7.2	3.3–20.6	< **0.001**	67.4	1.0	0.9–1.1	0.784	131.5
Average water salinity	3.0	1.9–6.2	< **0.001**	48.2	1.1	1.04–1.13	< **0.001**	112.4
Culture type				97.6				159.1
Monoculture	1				1			
Polyculture	12.4	4.4–37.8	< **0.001**		1.1	0.7–1.6	0.663	
Average percentage tilapia	excl				0.96	0.93–0.99	**0.014**	142.3
Average pond size	excl				1.02	0.96–1.08	0.448	158.7
Shared equipment practices								161.2
None	excl				1			
With 1 farm					0.97	0.7–1.3	0.846	
With 2 or more farms					0.94	0.7–1.4	0.751	
Average fish weight at mortality	n/a				0.99	0.99–0.99	**0.029**	153.9
Multivariable analysis								
Water source				41.5				
Mixed source	1	0.0003–0.06	< **0.001**					
Bore water or lake	0.007	0.4–118.6	0.238					
Irrigation canal or river	4.8							
Culture type								
Monoculture	1		**0.010**					
Polyculture	23.0							
Water source								98.5
Mixed source					1			
Bore water or lake					0.4	0.2–0.8	**0.010**	
Irrigation canal or river					1.4	1.2–1.9	**0.023**	
Average salinity					1.1	1.02–1.1	**0.007**	

Bold indicates P-values < 0.05
OR = odds ratio, AIC = Akaike's information criterion. Excl = excluded due to non-convergence of model, n/a = non applicable.

chlorine, agricultural lime, probiotics, some unlabelled disinfectants and farmer recipes.

About 75% of farmers indicated that they removed dead fish once or several times per day. Different methods of fish disposal included burning (27%), burying on farm (9%). The majority (39%) combined several methods such as burning, burying and selling, depending on the amount of lost fish. A number of farmers (10%) removed dead fish from the pond and left them unattended on the ground near the pond without additional action. About 15% reported that it was rare to see dead fish in their ponds, so no disposal method was reported. Fig. 8 summarizes the different methods used by farmers for disposal of dead fish. The use of vaccines for disease prevention was not reported by any farmer.

3.9. Assessment of risk factors associated with tilapia mortality

Assessments of baseline characteristics associated with the occurrence of unusual mortality show that governorate group (north/south), water source, average water temperature, average water salinity, culture type, average pond size, equipment sharing practices and average percentage of tilapia present in the pond were significantly associated with the occurrence of unusual mortality ($p < .001$). These findings were further supported by the results from the regression models. In the univariable regression analyses the factors governorate group, water source, average water temperature, average water salinity and culture type were found to be significantly associated with the occurrence of unusual mortality ($p < .001$, Table 4). Due to a moderately high correlation between governorates and water source, water source was chosen for inclusion in the multivariable regression due to it being deemed to contain more biologically-plausible information. The final model, containing water source and culture type is shown in Table 4. Farms using borehole or lake water were significantly less likely to experience unusual mortality events compared to farms using mixed water sources or irrigation canal or surface water. Farms practicing polyculture were also significantly more likely to experience unusual mortality, even after adjustment for water source.

Assessments of baseline characteristics associated with the level (%) of unusual mortality indicated that governorate group (north/south) ($p = .026$) and water source ($p < .001$) were significant (Table 2). Further assessment of the univariable regression analyses found the following factors significant ($p \leq .029$): governorate group (north/south) ($p < .001$), water source (≤ 0.001), average water salinity ($p < .001$), average percentage tilapia in the pond ($p < .014$) and average fish weight at mortality (Table 4). Water source was again selected for inclusion in the multivariable regression analyses, with water source and average water salinity remaining in the final model (Table 4). In line with the occurrence of unusual mortality events, farms using borehole water or lake water were likely to have significantly lower mortality levels during an outbreak compared to farms using other water sources. In contrast, farms using irrigation canal or surface water were likely to have significantly higher mortality levels during an outbreak. Increasing salinity was associated with an increase in mortality level, even when adjusted for water source.

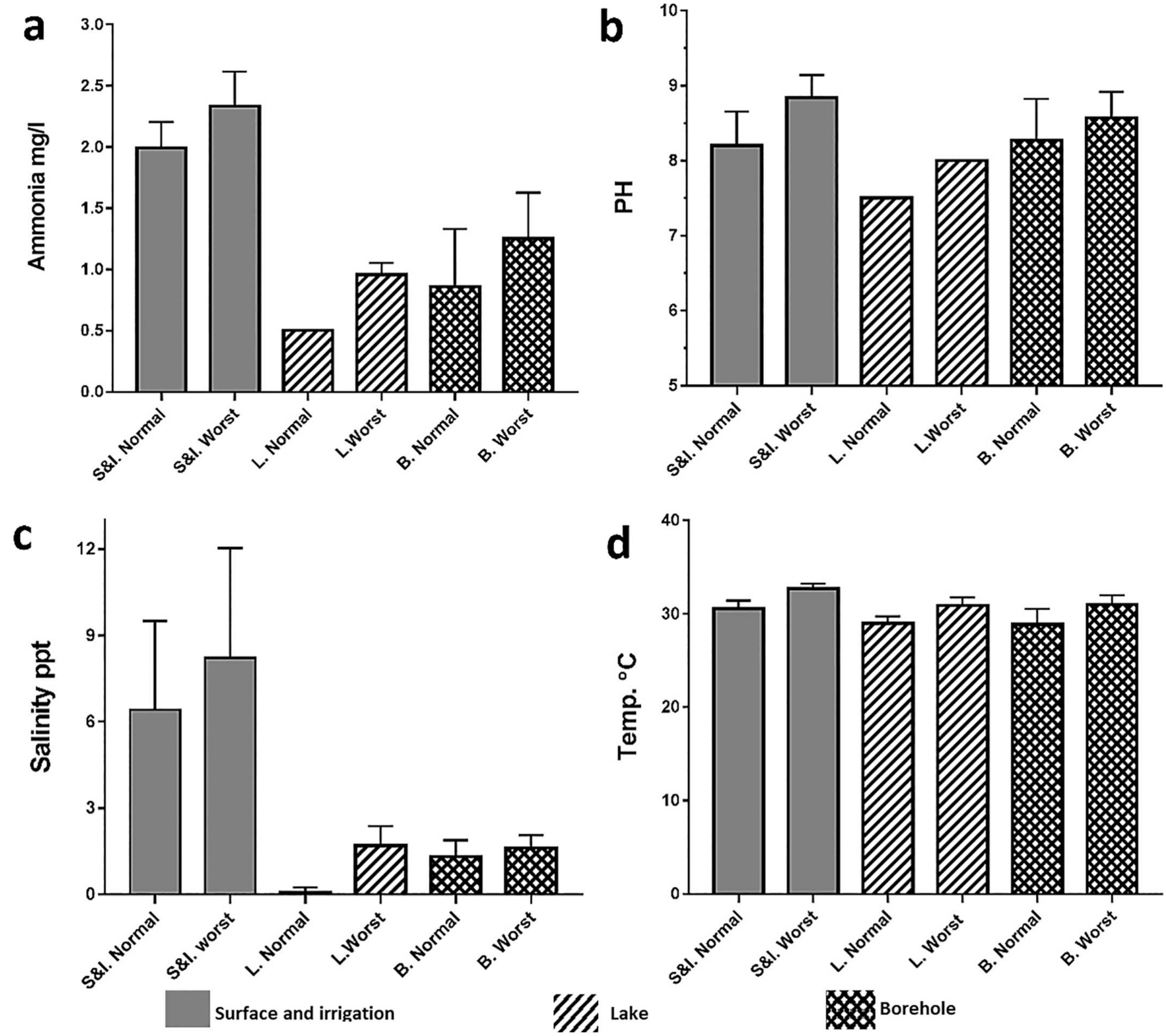

Fig. 6. Water quality parameters in different governorates in relation to water source (surface and irrigation, lake, borehole water) reported by technical support providers under normal conditions and under the worst conditions. (a) ammonia, (b) PH, (c) salinity (ppt) and (d) temperature (°C).

Fig. 7. Red patches were the major clinical sign observed on tilapia farms affected with unusual mortalities. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

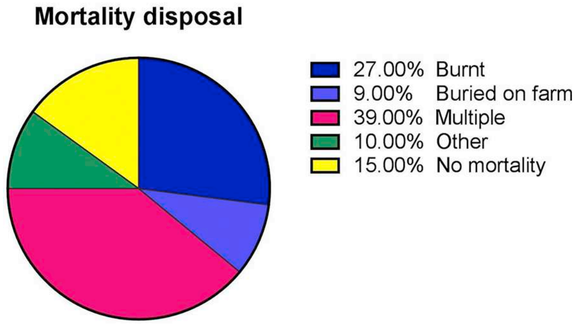

Fig. 8. Different methods used by farmers to dispose of dead fish on farms affected by unusual mortality.

3.10. Economics and economic impact of disease

All farms sold their fish to the local market and used some for their own consumption. While most farmers (76%) used wholesalers as the preferred retail route, 7% used wholesalers in combination with other outlets, 8% used middle men and 9% had their own outlets.

The average cost of seed was 0.1 EGP for 90.2% of the farms across all governorates, including the two farms that sourced seed from their own stock. Hatchery prices ranged from 0.07 to 1.3 EGP/individual seed depending on seed size. All farms used commercial feeds, with one farm also using additional homemade feed. Feed costs ranged from 8.7 to 10 EGP per kg.

The average estimated production costs per kg of tilapia ranged from 17.4 to 19.0 EGP in farms reporting no unusual mortality events and 17.7 to 19.5 EGP in farms reporting unusual mortality. The average and total production costs and losses due to normal and unusual mortality are presented in Tables 5 and 6 respectively.

Twelve farms from Kafr El Sheikh and Faiyum governorates without unusual mortality gave estimates on the total losses (kg) of tilapia due to baseline mortality and the expected farm gate price of lost fish (EGP/kg) if the fish had survived. Overall, the losses from baseline mortality totalled 69,050 EGP (around 4400 USD).

All the 89 farms that had experienced unusual mortality gave estimates of the total losses (kg) of tilapia due to unusual mortality and the expected farm gate price (EGP/kg) if the fish had been sold at the weight at which it died. Overall, for these farms, the estimated losses from unusual mortality totalled 11,304,400 EGP (around 720,000 USD).

4. Discussion

The present study was undertaken to determine key farming practises and identify risk factors contributing to tilapia mortality in Egypt. Results from our 2018 cross sectional survey of farms located in four top tilapia producing governorates and one with less farming activities indicated that water source and quality (irrigation and surface water without prior filtration or treatment) were the most prominent contributing factors to both occurrence and intensity of unusual mortality events. Other risk factors included *co*-cultivation or polyculture of tilapia with other fish species collected from the wild (e.g. mullet). We observed limited biosecurity measures across affected farms.

Egypt is the largest fish producer in Africa and the eighth globally (Eltholth et al., 2015) with total production of over 1.8 million tonnes, 1.5 million tonnes coming from aquaculture and about 370,000 t from natural fisheries (GAFRD, 2017). Therefore, aquaculture in Egypt contributes significantly to income, employment creation and provides food and nutrition security (Feidi, 2018; Nasr-Allah et al., 2020). Egypt is the third largest producer of Nile tilapia (*Oreochromis niloticus*) after China and Indonesia. Nile tilapia dominates other cultured fish species representing 59.4% of total fish production in 2017 (GAFRD, 2017).

Table 5
The average and total production costs associated with purchase of seed, feed, biosecurity, and losses due to normal mortality.

Farms with only normal mortality

Governorates	Average Production in kg (Total production in kg)	Average overall production cost in EGP (Total cost in EGP)	Specific Production costs Average (total)						Baseline mortality losses	
			Average seed costs (Total cost in EGP)	Seed % of average Prod. cost	Feed costs	Feed % of average Prod. cost	Average biosecurity and sanitation cost in EGP (Total cost in EGP)	Biosecurity and sanitation % of average Prod. cost	Average mortality losses in kg (Total loss in kg)	Average value of lost fish (number of dead fish * expected farm gate price) in EGP (Total value in EGP)
Faiyum (n = 15)	48,267 (724000)	916,133 (13742000)	48,140 (722100)	5,3%	632,533 (9488000)	69,0%	6487 (97300)	0,7%	330[a] (4950)	6683[a] (60150)
Kafr (n = 2)	9000 (18000)	162,000 (324000)	4500 (9000)	2,8%	135,000 (270000)	83,3%	1700 (1700)	1,0%	495 (700)	4450 (8900)
Minya (n = 7)	3286 (23000)	57,429 (402000)	4043 (28300)	7,0%	37,250 (260750)	64,9%	93 (650)	0,2%	n/a[b]	n/a[b]
Total (n = 24)	765,000 kg	14,468,000 EGP	759,400 EGP	5,2%	10,018,750 EGP	69,2%	99,650 EGP	0,7%	5650 kg	69,050 EGP

[a] n = 10 as 5 farms reported "0" kg for baseline mortality.
[b] All 7 farms reported "0" kg for baseline mortality.

Table 6
The average and total production costs associated with purchase of seed, feed, biosecurity, and losses due to unusual mortality.

Farms with unusual mortality										
Governorates	Average Production in kg (Total production in kg)	Average overall production cost in EGP (Total cost in EGP)	Specific Production costs Average (total)						Unusual mortality losses	
			Average seed costs (Total cost in EGP)	Seed % of average Prod. cost	Feed costs	Feed % of average Prod. cost	Average biosecurity, sanitation, chemicals, veterinary and disposal cost (Total cost in EGP)	Biosecurity, sanitation, chemicals, veterinary and disposal cost % of average Prod. cost	Average mortality losses in kg (Total loss in kg)	Average value of lost fish (number of dead fish * expected farm gate price) in EGP (Total value in EGP)
Beheira (n = 32)	30,609 (979500)	550,016 (17600500)	26,546 (849480)	4,8%	589,375 (18860000)	**107%**	6710 (208000)[a]	1,2%	10,047 (321500)	131,609 (4211500)
Faiyum (n = 2)	27,000 (54000)	530,000 (1060000)	14,500 (29000)	2,7%	385,000 (770000)	72,6%	5500 (11000)	1,0%	800 (1600)	9700 (19400)
Kafr El Sheikh(n = 48)	53,281 (2557500)	995,240 (47771500)	28,958 (1390000)	2,9%	893,883 (42532000)	89,8%	7207 (302700)[a]	0,7%	9094 (436500)	126,135 (6054500)
Minya (n = 1)	7500 (7500)	135,000 (135000)	3600 (3600)	2,7%	140,000 (140000)	**104%**	100 (100)	0.1%	2000 (2000)	34,000 (34000)
Sharqia (n = 6)	36,833 (221000)	681,500 (4089000)	30,533 (183200)	4,5%	682,917 (4097500)	**100%**	8300 (41500)[a]	1,2%	12,167 (73000)	164,167 (985000)
Total (n = 89)	3,819,500 kg	70,656,000 EGP	2,455,280 EGP	3,5%	66,399,500 EGP		563,300 EGP	0,8%	834,600 kg	11,304,400 EGP

Bold indicates P-values < 0.05
[a] Some farms stated "0" in biosecurity costs, leaving the following numbers: Beheira n = 31, Kafr El Sheikh n = 42, Sharqia n = 5.

Other cultured species grown in ponds include mullet (13.49%), carp (10.37%) and African catfish (2.4%), seabass and seabream (3.7%) (GAFRD, 2017). Most of the fish production in Egypt comes from the private sector (GAFRD, 2012).

In the present study, no women were found to be involved in any farming activities either full or part time. Similar findings were made by Nasr-Allah et al. (2020) and Dickson et al. (2016a) who indicated that women worked only in retailing business or fish processing. Each farm employed, on average, 2.3 full-time all male staffs and 1.5 part-time staffs. This emphasizes the significant role that aquaculture plays in employment and job creation. We found a positive relationship between unusual mortality events and years of farming experience. However, this factor was excluded since years of farming experience seemed to be confounded within governorate. For instance, in Minya, few farms reported unusual mortality events, although the few cases were because of limited farming experience. While not consistent in all analyses, we found an indication of larger pond sizes being associated with unusual mortality, as reported by Yanong (2013) who indicates that very large pond sizes make any assessments (feeding behaviour and health observations) of the general fish population more strenuous during the initial stages of a disease outbreak. This is in addition to the burden of disinfection costs which increases with large pond sizes (Yanong, 2013).

Co-cultivated species in polyculture systems represent potential risk factors as shown in the present study. Mullet was the predominant co-cultivated species with tilapia, present in 100% of the farms that reported unusual mortality. This is mainly because mullet culture is heavily dependent on wild caught-seed that can act as asymptomatic carriers of pathogens that could be transmitted to tilapia leading to serious diseases (Sadek and Mires, 2000; Saleh, 2008). None of the affected farms had considered sending mullet samples for laboratory health examination before introducing them with their tilapia stocks.

Our results showed that water source is the most prominent contributing factor leading to occurrence of unusual mortality. The scarcity of land and water resources dedicated for aquaculture is a problematic issue in Egypt (Eltholth et al., 2015) since fish farm operations are only permitted on "sterile" land (Shaalan et al., 2018). On top of that, Egypt law allows only drainage water from agricultural activities to be used for aquaculture purposes. This has serious implications on water quality as contaminants get transferred to fish production systems (Shaalan et al., 2018). Quality of irrigation water quickly deteriorates with the extensive use of fertilizers and pesticides in agriculture, which in turn contaminate local surface and borehole water bodies as nitrates leach from fertilizers and bacteria from livestock faeces and feed wastes (Ezzat et al., 2002; Mohamed et al., 2013). The exact water exchange rate was difficult to determine since it varies with incoming water quality, season and water temperature.

The majority of farmers stock their ponds once a year, but harvests happen at different times to match consumer demand for live fresh fish sold in markets and also to reduce fish losses in the absence of cold chain facilities (Macfadyen et al., 2011). In the present study, stocking density varied from one area to another depending on water quality. No relation between average stocking density and occurrence of unusual mortality was found. However, it seems that not all-male sex-reversal was effective as huge numbers of newly hatched fry were observed during sampling, resulting in overpopulated ponds. On the other hand, farmers from Minya governorate, who reported using borehole water, had the highest stocking density with the least cases of disease outbreaks. This indicates that occurrence of unusual mortality is influenced by multiple interlinked factors rather than a single aetiology. Fish feed contributes to about 75 to 85% of the production cost (Dickson et al., 2016b; Shaalan et al., 2018). Almost all farmers reported using commercial feed sourced from 15 different aquafeed producers. Because of the increase in the number of feed mills and their availability, farmers do not have to store feed stock for long periods of time. It is well known that pathogens can transmit to fish through poor quality feed (Terech-

Majewska, 2016). This could explain the start of disease outbreaks following the change of feed source as reported by few farmers. Anecdotally, many farmers reported that fatty fish were usually affected first during the unusual mortality events. During post mortem examination of some of those affected fish, lots of visceral fats were detected. This is probably attributed to improper feed formulation (imbalanced feed ingredients), excessive feeding rates or variation in the size of stocked fish (Shefat and Abdul Karim, 2018). Very few farms reported strong biosecurity measures on arrival of new stock (fish disinfection and quarantine in isolated tanks before stocking), although they also have experienced unusual mortality. Avoiding equipment sharing between farms was found to be significantly associated with a lower probability of experiencing unusual mortality event. Pond drying following harvest was the most commonly used biosecurity practice by farmers between production cycles either used alone or combined with other practices such as liming and/or net cleaning. Farmers in Minya grew fish in water stored for crop irrigation, therefore, pond drying was not implemented there.

Based on experience in previous production cycles, most farmers expressed their concerns on the ongoing “summer mortality syndrome” problem. The majority of cases usually start gradually during July and persist for more than a month. Basically, tilapia is the main affected species, however, mullet were also affected in rare cases after tilapia. Clinical signs of disease include mainly red patches on the skin, tail and fin erosion and exophthalmia in some cases. Most farmers attributed those mortalities to deteriorated water parameters in addition to increase water temperature during the summer months. Normally salinity is expected to increase during summer because of higher evaporation rate and subsequent reduction in oxygen solubility in water (Ahmed and Abdel-Rahman, 2011).

Ammonia level is also expected to increase for the same reason in addition to its elevation as a result of excessive feeding rates. It is well known that water parameters can influence the growth, reproduction and health status of aquatic animals (Ahmed and Abdel-Rahman, 2011). Most pathogens in the aquatic environment are opportunistic, causing disease in immune suppressed fish, therefore, deteriorated water can increase fish susceptibility to different pathogens. In this study, the highest averages recorded for water salinity, and ammonia were associated with water coming from irrigation canals and surface water. All these factors including excess feeding rates to achieve maximum weight gain to reach market size faster are among the principal stressors that favour disease outbreak. Reported actions practiced by farmers in response to unusual mortality events were either to stop feeding altogether or reduce the amount of given feed. However, these seem to give only temporary reduction in mortality levels as mortality goes back up once feeding rate returns to normal.

Increasing water flow rate is also a common practice used by farmers when incoming water quality is good. Following unusual mortality events, few farmers consulted veterinarians and feed companies that offer technical support to promote their products. Many unlabeled products are sold to farmers over the counter, with no or limited documentation on their safety and efficacy.

Several methods for dead fish disposal have been reported by farmers. Depending on the amount of dead fish, they were burnt, buried onsite, sold to companies or left unattended near the pond. The methods used by farmers to dispose of their dead fish are generally not appropriate. This emphasizes the importance of biosecurity training for farmers.

Even though vaccination can be a very effective control measure to prevent diseases, no commercial vaccines were available for use when our data were collected. Additional observations were made on the presence of predators, pets and large animals moving freely between farms, all representing potential health and biosecurity risks. Our results indicate that biosecurity consists of several interlinked components that are working together. Applying one of them and ignoring the rest will not have the full benefit to prevent and reduce the occurrence of unusual mortality.

In order to estimate potential economic losses associated with unusual mortality, relevant production costs for feed, seed, biosecurity, health consultation and medication were investigated. For labour costs, no accurate estimates were provided since most farmers are self-employed, therefore, it has been excluded from the analyses. Instead, total production cost to produce one kilogram of tilapia was included. In Egypt, fish feed generally accounts for about 70–95% (85% in average) of total farm operating costs (Soliman and Yacout, 2016). In this study, the specific production costs (feed, seeds and biosecurity) for farms affected by unusual mortality have exceeded the total production cost in Sharqia, Minya and Beheira (100%, 104% and 107% respectively). This is mainly because the estimation of total production cost was based on the amount of net production excluding specific production cost for lost fish.

5. Conclusion

The present study indicates that several factors are likely contributing to occurrence of mortality in farmed fish. Implementation of biosecurity measures and improving farming practices, should help to reduce mortality incidence and severity in affected farms. In addition, policy changes are needed to ensure priority is given to fish farms to use fresh water ahead of crop farming to reduce incidence of mortalities caused by sub-optimal water quality.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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