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Effect of Gonadal Maturation on the Proximate Composition: A Case Study on the Nile tilapia and African Catfish in Burullus Wetland, Egypt

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ABSTRACT

The current study focused on the Nile tilapia (*Oreochromis niloticus*) and the African catfish (*Clarias gariepinus*) in Burullus Wetland. It aimed to investigate the stages of sexual maturity and their effect on the biochemical components of muscle tissue (the edible part) by obtaining 410 individuals with a length range of 8-25cm for the Nile tilapia and 132 individuals with a length range of 17-51cm for the African catfish. The percentage of each maturity stage varied significantly according to seasons (t-test, $P<0.05$) for both species. The advanced stages of maturity reached the highest mean percentages during summer, followed by spring, and the extended presence of the advanced stages makes both species have a prolonged spawning season. The mean values of the gonadosomatic index (GSI) varied significantly between seasons, and both species peaked during the summer season, indicating a period of intense activity. The values of the biochemical components of the muscles differed significantly according to whether seasonal mean values of GSI or even maturity stages. By engaging in the reproductive activity, a highly significant correlation was observed between the biochemical components of muscle and sexual development, represented by the GSI value. This correlation was positive for moisture content and negative for the rest of the components.

INTRODUCTION

In the far north of the Nile Delta and between the arms of the great River Nile, one of nature's masterpieces in the eastern Mediterranean region lies. It is Burullus Wetland, one of Egypt's wealth, both environmentally and productively. The wetland is distinguished by its unique location with an area of 465km^2 **(KBA, 2023)**. Its unique biodiversity motivated it to be declared a nature reserve and subject to the Ramsar Convention for the Wetlands Conservation **(El-Betar, 2017)**. The water depth ranges from 0.6 to 2.0m with an average depth of 1.25m. The Burullus Wetland has a wide range of water salinity (0.69- 11.4‰), reaching its maximum in the far northeast due to the lake's connection to the Mediterranean Sea via Boughaz El Burullus, while the lowest salinity is in the far west, where the Birnbal Canal supplies the fresh water of the Nile Rosetta Branch **(Radwan *et al*., 2022)**. Except for the northern edge, Burullus Wetland is surrounded by 8 drains and receives 2.5 billion m^3 of wastewater annually **(El-Naggar & Rifaat, 2022)**. The varying degrees of salinity lead to a wide biodiversity of species **(El-Betar, 2017)**. Fortunately, Burullus Wetland has undergone a governmental development project (2017-2021), which led to clearing, deepening and increasing the open water area **(Radwan *et al*., 2022)**. With an annual production of 91852 metric tons (MT), Burullus Wetland is the highest in production and fertility compared to the rest of the Egyptian northern lakes (**LFRPDA, 2021)**. In this context, the Nile tilapia (*Oreochromis niloticus*) is considered the basis of fish production in Egypt and many countries of the world, and consumers desire it wherever it is found. Egypt produces 1114265 MT annually, representing 55.4% of the total annual production **(LFRPDA, 2021)**. It also constitutes 60.4% of Burullus Wetland' production **(LFRPDA, 2021)**. On the other hand, the African catfish (*Clarias gariepinus*) ranks fourth among the Egyptian produced species, with a production of approximately 50,000 MT annually **(LFRPDA, 2021)**. The African catfish represents an important food and protein source with a palatable taste and thorn-free muscle mass. The demand for it has increased recently due to its availability at a reasonable price in light of the successive economic crises.

Reproduction means the survival of the species; its successful achievement is what guarantees the continuation of life **(Omotosho, 1993)**. Studying the stages of gonadal maturity is of great importance in fisheries assessment, the applications of which are detecting the size at sexual maturity and the size of mature stock **(Bagenal, 1978)**. Clarifying the maturity stages and their precise timing is the basis for legislation related to prohibiting and allowing fishing **(Goncalves *et al*., 2006)**. On the other hand, the development and maturation of gonads is one of the most complex biological operations for fish since it is closely linked to a variety of ecological variables necessary for releasing the secretion of sexual hormones and thus the launch of the gonads toward development. At this stage, the body's vital energy is directed toward gametogenesis. Many studies have been conducted on the reproductive aspects of the Nile tilapia and the African catfish **(Peterson *et al*., 2004; Ameha *et al*., 2006; El-Betar, 2009; El-Zoghby *et al*., 2010; Dadebo *et al*., 2011; Rizzo; Bazzoli, 2019)**. How does the muscle tissue, the edible part of thetilapia and catfish, respond to gonadal maturation? The current study aimed to provide clarification through proximate analysis.

MATERIALS AND METHODS

- Sampling

Sampling of *Oreochromis niloticus* and *Clarias gariepinus* was carried out seasonally during the 2022 fishing season from the eastern sector of Burullus Wetland (Fig. 1) with a total number of 410 specimens (192 male and 218 female) and 132 (59 male and 73 female) for both the given species, respectively. Regarding the Nile tilapia, the fishing gear of Lokkaffa was relied upon to collect samples, which was clarified as non-selective dredge gear. Meanwhile, gillnets were relied upon to collect the African catfish samples. Additionally, the harpoon was also used for catching in shallow waters at the time of mating and spawning.

- Measurements

After collecting samples of both studied species, they were transported in a cooled form to the laboratory. For each individual, the total length was measured to the nearest 0.1cm and the total weight to the nearest 0.1 gram. The dissection was performed, and the gonads were carefully separated then weighed to the nearest 0.01 gram. The macroscopic examination was applied to determine the sex and the exact stage of gonad development, which were identified according to **Gokhale (1957)** (Table 1), with some modifications in the morphological description carried out to suit both studied species.

The frequency distribution of length was explained by calculating the percentage of individuals within each length group and representing it graphically.

Gonadosomatic index (GSI) was calculated by using the formula; GSI = GW/TW*100 **(Busacker *et al.*, 1990)**, where GW was the gonad weight (g) and TW the body weight (g).

- Tissue analysis

A biopsy of dorsal muscle, about 10 grams from the right-side, was separated for proximate analysis. Muscle samples were accurately minced to achieve complete homogeneity using an electric homogenizer model Hinotek instrument D500. Moisture, lipid, crude protein and ash content were measured according to methods described in **AOAC (2005)**. The sample was analyzed in triplicate to ensure accuracy and avoid error. The analysis was performed based on the wet weight of the tissue.

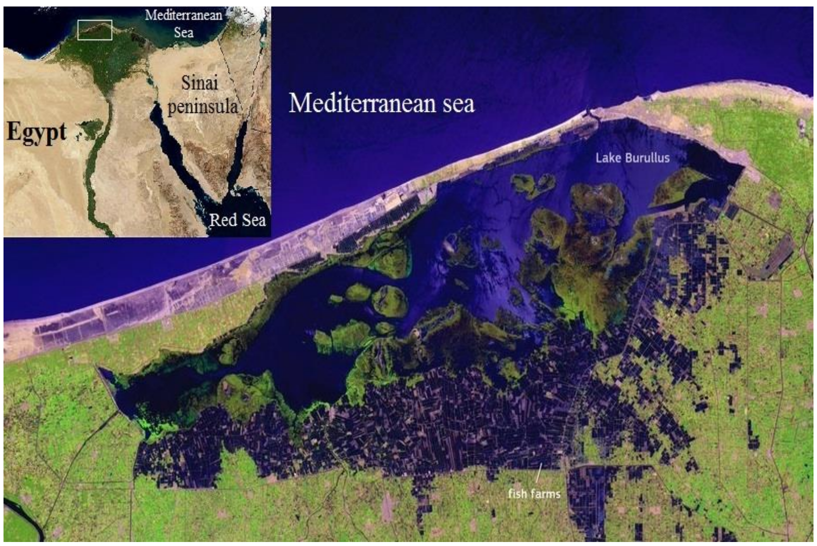

Fig. 1. Satellite location map of Burullus Wetland, Mediterranean lagoon, Egypt

- Moisture content

The moisture content was estimated by drying 2 grams of the sample at a temperature of 105°C overnight until the weight was constant, and then cooled in a desiccator. The moisture content was calculated from the equation: moisture content = (weight before drying - weight after drying)/weight before drying * 100. Samples were dried by using the drying oven model BINDER® ED 400.

- Crude protein

Crude protein was determined by digesting 2 grams of the sample in 25ml of conc. H_2SO_4 + a mixture of powdered potassium sulphate, copper sulphate, and selenium mixed in the ratio of 94.8: 5: 0.2 until the color became clear, then cooled and diluted with 40% sodium hydroxide to 100ml. The sample was distilled in Kjeldahl distillation unit model Vilitek® AKV-10, and then titrated with 0.2 N HCL. The result expressed the total nitrogen content. The following equation was applied to derive crude protein:

$$\% \text{ Protein} = \frac{(\text{titre vol sample} - \text{titre vol blank}) \times 0.014 \times 0.1 \times 6.25}{\text{Weight of sample used}} * 100.$$

Table 1. The scale of maturity stages and the gonadal virtual diagnosis according to Gokhale (1957) with modification

Stage no.	Stage	Macroscopic (Virtual) diagnosis	
		Male	**Female**
I	**Immature virgin**	Testes are transparent, elongated threads and extend close to the kidney.	The ovary is small, thin and transparent. It occupies an almost insignificant portion of the abdominal cavity. It is often difficult to distinguish between the sexes.
II	**Developing and Recovering**	Testes are thicker than the previous stage, milky pale pink in color and can be distinguished into testes or ovaries.	The ovary increased slightly in size and rounded with very fine, almost invisible ova. Recovering spent ovary may appear reddish-brown.
III	**Maturing**	Testes gain more size; milky white in color and they extend to nearly half of the abdomen cavity.	The ovary is slightly swelling, opaque or pal yellowish in color. Eggs are small but easily visible as white granules. The ovary occupies about half the length of the abdominal cavity.
IV	**Mature**	Testes extend to about two thirds of the abdomen cavity with a more whitish color.	The ovary occupies about two thirds of the abdomen cavity with spherical yellow ova in tilapia and reddish brown in catfish.

V	**Ripe**	The testes are turgid at this stage. The color is still more milky white.	The ovary increases in size and occupies the majority of the abdomen cavity. Larger eggs can be distinguished characters. The color turns to light green in the catfish and yellowish in the tilapia.
VI	**Spawning**	Testes are more swollen and have the same color. Semen flows out with light pressure on the abdomen.	Spawning is running and eggs are almost shed. The eggs are easily expelled by light pressure on the abdominal wall. The ovaries are swollen, and the eggs are in their peaked size.
VII	**Spent**	Testes are soft, empty and the testes become flat creamy white and flaccid in structure.	The ovary is flaccid and much reduced in size. The ovaries begin to shrink with blood red color in tilapia and dark brown in the catfish.

-Crude lipid

Crude lipid was estimated by subjecting a known weight of the sample to multiple cycles of extraction, 6 hours, using petroleum ether to separate the lipid from the sample by using the Soxhlet Extraction Unit model JAPSON® JA21833. The loss in weight after extraction is the weight of the crude lipid in the sample, and its percentage was determined from the equation: (weight of lipid/weight of sample before extraction)*100.

- Ash content

To determine the ash content in the muscle samples, a known weight of the sample is burned in a Muffle Furnace (model EDS-MTLE-11467) at a temperature of 550°C for 12 hours. After burning, the remaining residue was the ash, which represents the inorganic mineral content of the sample; its percentage was determined from the equation: (weight of ash/weight of sample)*100.

- Statistical analysis

Descriptive analysis, t-test, standard deviation and student error were performed. The SPSS program, version 16, was used for Windows 7. The differences in means were tested at a significance level of 0.05.

RESULTS

1- Length frequency distribution

The community of *Oreochromis niloticus* in Burullus Wetland was represented by individuals with a length range of 8.0-25.0cm. The predominance was achieved for sub-medium sizes, with individuals belonging to the length groups of 12.0, 14.0, and 13.0cm, constituting 12.7, 11.3, and 10.5%, respectively (Fig. 2).

A wide range of length was observed for *Clarias gariepinus*, from 17.0 to 51.0cm. No absolute dominance of a specific length class was observed. Although, the numerical frequency tends to highlight classes 43, 42 and 45cm as having the largest percentage (7.4, 6.8 and 6.1%, respectively) (Fig. 3).

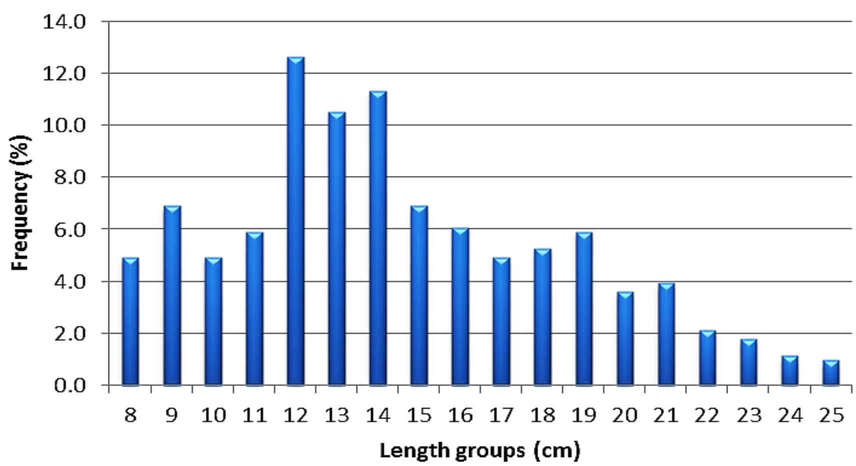

Fig. 2. Length frequency distribution of *Oreochromis niloticus* in Burullus Wetland, Egypt

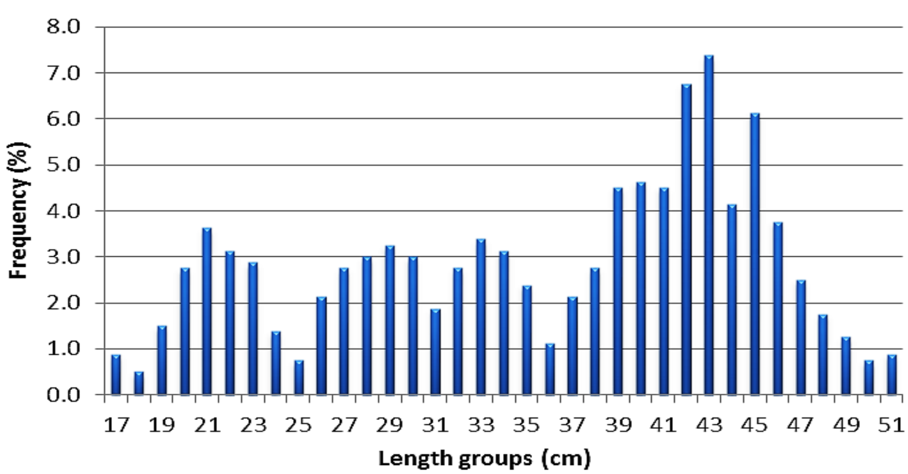

Fig. 3. Length frequency distribution of *Clarias gariepinus* in Burullus Wetland, Egypt

2- Gonadosomatic index (GSI)

The gonadal growth and their variation in size over the seasons were monitored. Regarding the Nile tilapia, the results showed that males and females agreed in reaching the peak during summer, with the mean values of GSI being 0.48± 0.06 and 3.61± 0.39 for males and females, respectively, as winter represents the rest season (Fig. 4). According to seasons, the mean values of GSI varied significantly (t-test, $P<0.05$) for both sexes.

Concerning the African catfish, spring and summer showed seasons of high GSI. Males testes reached their maximum weight during the late spring (mean 0.29± 0.03), while females were in the summer season with the mean value of 2.19± 0.10. The rest gonads were obtained in autumn and winter for males, and mainly in autumn for females (Fig. 5). For both sexes, the seasonal mean values of GSI showed a significant variation (t-test, $P<0.05$).

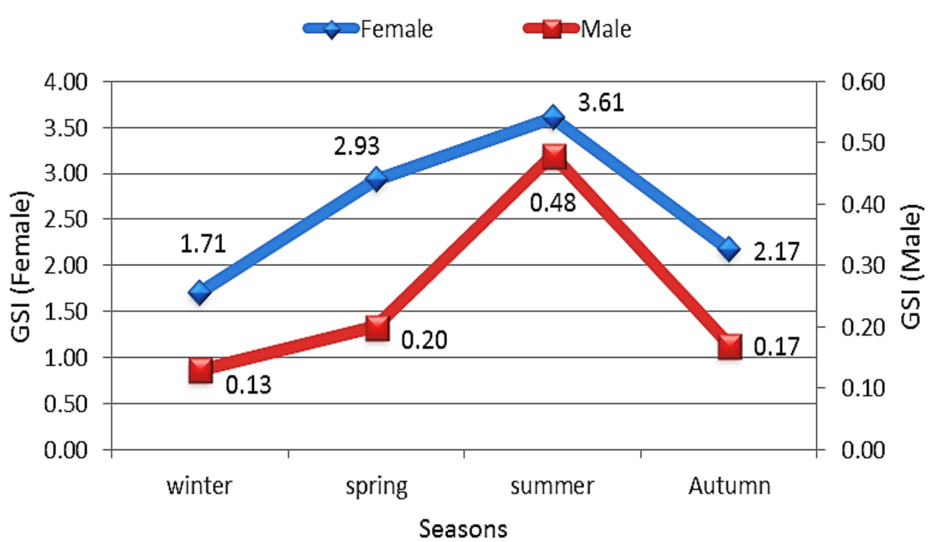

Fig. 4. Seasonal variations in gonadosomatic index (GSI) for male and females of *Oreochromis niloticus* in Burullus Wetland, Egypt

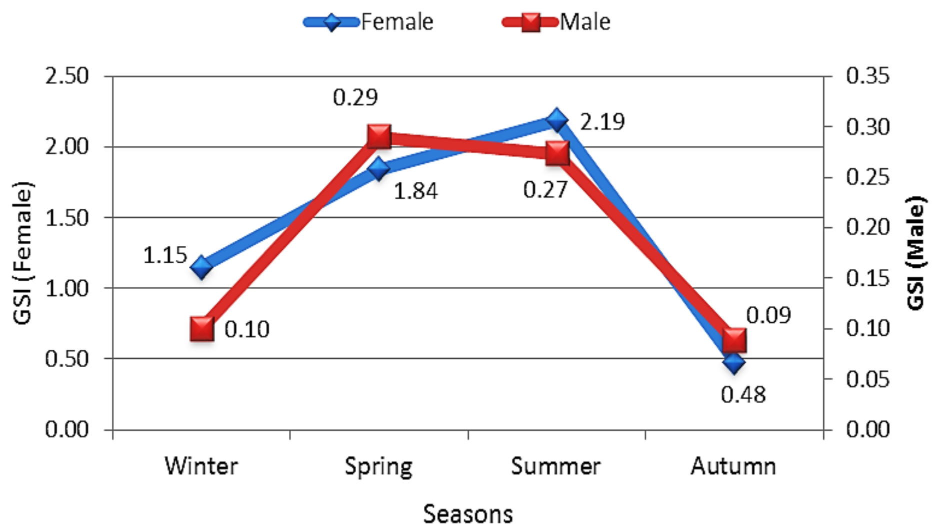

Fig. 5. Seasonal variations in gonadosomatic index (GSI) for male and females of *Clarias gariepinus* in Burullus Wetland, Egypt

3- Seasonal distribution of maturity stages

3-1- Oreochromis niloticus

According to seasons, the male and female gonads took a consistent pattern during the winter; most of the gonads were in the initial stages of maturation (immature, developing and maturing), while gonads in the advanced stages were in the lowest percentage, thus indicating the resting season. During the spring season, the percentage of gonads beginning to prepare for maturation increases, as gonads belonging to stage 3 (maturing) occupy 46.1 and 26.8% for males and females, respectively. The percentage of gonads in the ripe stage also increased significantly. With the increase in temperature and the onset of summer, the gonads of stage V (ripe stage) reach their maximum percentage, representing 16.2 and 21.5% of the gonads of males and females, respectively. As the temperature gradually decreases during autumn, the ripe gonads decrease sharply, and the empty gonads (spent stage) appear at the highest percentage ever (Fig. 6).

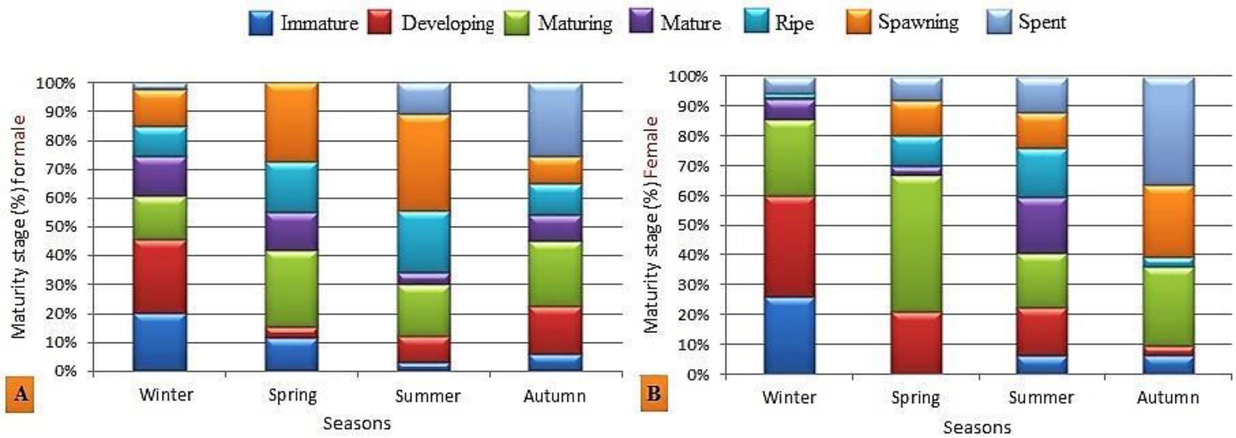

Fig. 6. Seasonal distribution of maturity stages for **(A)** male and **(B)** female of *Oreochromis niloticus* in Burullus Wetland, Egypt

3-2- Clarias gariepinus

Males and females showed agreement in the general distribution pattern of maturity stages. During winter, most gonads belonged to the first three stages of maturity, as they together represented 80.9 and 60.2% for females and males, respectively. By spring, the gonads develop rapidly and appear at advanced stages of development, at which point the gonads of the ripe stage appear with the highest percentage representation, 32.8 and 22.3% for females and males, respectively. It is also noted that there is a sharp increase in empty gonads (spent stage) by more than 20% for both sexes. The gonads are negatively affected by the fall season, as the percentage of sexually active gonads decreases, and the percentage of ripe ovaries decreases to the lowest percentage, with a complete absence of ripe testes (Fig. 7).

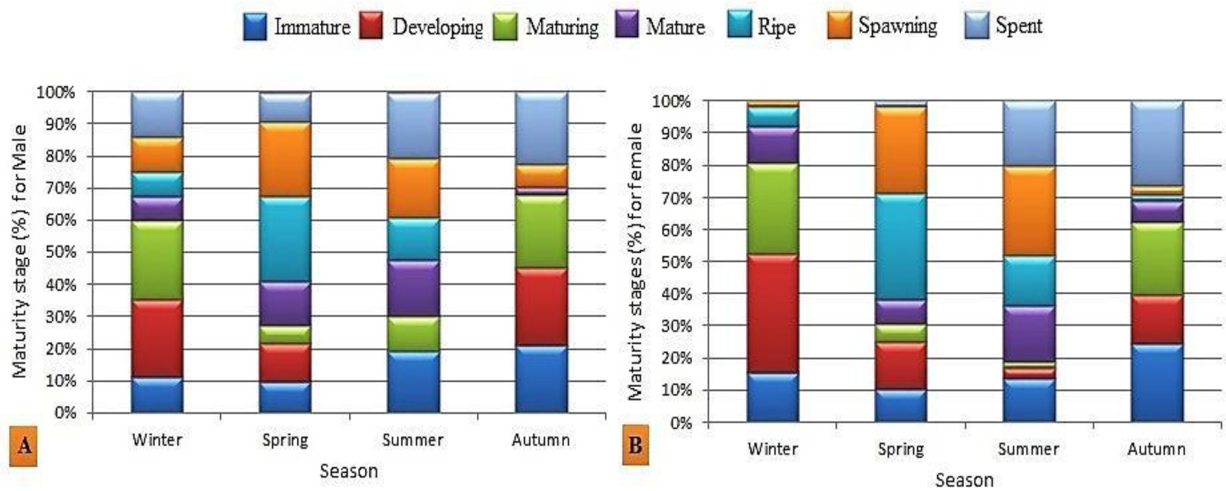

Fig. 7. Seasonal distribution of maturity stages for **(A)** male and **(B)** female of *Clarias gariepinus* in Burullus Wetland, Egypt

4- Proximate composition

4-1- Biochemical constituents according to maturity stages

The results shown in Table (2) explain the mean percentages (±SE) of muscle tissue analysis against the stages of gonad maturation for both sexes of *Oreochromis niloticus* and *Clarias gariepinus*, respectively. Both sexes showed consistency in the response of muscle tissue to changes occurring in the gonads during development. The harmony was not limited to the sexes of the same species but rather extended to both species under study.

4-1-A- Moisture

The results showed a coincident trend in the mean values of males and females. The lowest values of moisture content were recorded in the muscle tissue of immature individuals and individuals with gonads in the recovery stage. As the growth of the gonads progressed, a gradual increase in the moisture content of muscle tissue was observed.

4-1-B- Crude protein

The pattern of consistency between sexes continued in the average values obtained for crude protein in muscle tissue. In contrast to the moisture content, the highest average value was recorded with the appearance of the recovering gonads (developing stage). As the gonads mature and development increases, protein levels decrease significantly in the muscles of both sexes.

4-1-1-C- Lipid

The highest value of lipid content in the muscle tissue was recorded during the developing stage, while the lowest one was recorded in individuals with fully mature gonads (ripe stage), which clarified an opposite trend (decreasing) with increasing maturity.

4-1-1-D- Ash

The decreasing pattern in the mineral content of muscle tissue continued with a steady increase in gonad development, although the severity of the changes in males was less than that in females.

Table 2. Proximate analysis (Mean percentages according to maturity stages) of *Oreochromis niloticus* and *Clarias gariepinus* in Burullus Wetland, Egypt

Oreochromis niloticus		Maturity stages								
	Parameter	Immature	Developing	Maturing	Mature	Ripe	Spawning	Spent	Mean	± S.E
Female	Moisture	75.63	77.41	75.52	77.89	80.07	81.52	80.93	78.42	1.147
	Protein	16.03	17.82	16.77	16.7	14.04	14.92	15.64	15.99	0.822
	Lipid	2.11	3.37	3.06	2.76	1.93	2.32	2.22	2.54	0.319
	Ash	1.78	3.17	2.82	2.88	1.91	1.44	1.85	2.26	0.385
Male	Moisture	76.17	78.20	79.00	79.00	80.41	80.11	78.13	78.72	0.87
	Protein	16.66	17.84	17.72	16.07	15.72	16.26	16.90	16.74	0.44
	Lipid	1.92	2.71	2.55	2.07	1.56	1.88	1.73	2.06	0.29
	Ash	2.20	2.53	2.84	2.40	2.12	2.00	2.30	2.34	0.18
Clarias gariepinus		Maturity stages								
	Parameter	Immature	Developing	Maturing	Mature	Ripe	Spawning	Spent	Mean	± S.E
Female	Moisture	74.18	74.77	75.14	76.22	76.51	77.1	76.4	75.76	0.66
	Protein	16.55	16.73	16.43	16.42	16.13	15.3	15.82	16.20	0.32
	Lipid	3.92	4.06	3.75	3.44	3.06	2.88	2.81	3.42	0.24
	Ash	3.72	3.74	3.66	3.6	3.28	3.12	3	3.45	0.13
Male	Moisture	72.17	72.44	72.82	72.87	74.41	75.19	74.90	73.54	0.22
	Protein	17.84	19.20	18.33	18.15	17.56	17.12	17.80	18.00	0.24
	Lipid	3.57	4.21	4.56	4.44	3.55	3.24	3.66	3.89	0.24
	Ash	2.68	2.98	2.95	3.14	3.22	3.26	3.28	3.07	0.14

4-2- Biochemical constituents according to seasons

The results presented in Table (3) show the response of muscle tissue to seasonal changes in the mean values of GSI. The results show that there is consistency in muscle response, whether according to sex or species.

During winter, moisture content reached its lowest mean value, fully in line with the lowest mean value recorded for GSI. On the contrary, the average values of protein, lipid, and ash appeared with high values and are considered the highest throughout the seasons. By the spring season, the gonads begin to become active and develop, and then the GSI value increases significantly. Moisture content is observed to increase, and the average percentage of protein, lipid and ash decreases in varying proportions. During summer, the gonads mature and reach the highest mean value of GSI for males and females. A continued increase in the percentage of moisture coincided with a gradual decline in the rest of the parameters, reaching their lowest mean values ever. By autumn, the GSI value decreases, followed by the moisture content and the rest of the parameters begin to increase slightly. In general, the correlation coefficient showed a significant correlation between the seasonal GSI value and most of the parameters belonging to the proximate composition (P< 0.05), and the correlation was positive with moisture and negative for the rest of the parameters. On the other hand, the studied items showed significant differences according to the seasons (t-test, P< 0.05) (Table 4).

Table 3. Proximate analysis (Mean percentages according to seasons) of *Oreochromis niloticus* and *Clarias gariepinus* in Burullus Wetland, Egypt

Oreochromis niloticus		Parameters				
	Season	Moisture	Protein	Lipid	Ash	GSI ± S.E
Female	Winter	75.41	17.82	3.37	3.17	1.71 ±0.12
	Spring	79.30	16.20	2.55	2.68	2.33 ±0.20
	Summer	81.35	14.04	1.93	1.44	3.61 ±0.22
	Autumn	77.61	15.73	2.88	1.92	2.17 ±0.18
Male	Winter	76.17	17.84	2.71	2.84	0.13 ±0.02
	Spring	77.88	17.07	1.70	2.60	0.32 ±0.01
	Summer	80.41	15.72	1.56	2.00	0.41 ±0.02
	Autumn	78.12	16.63	2.50	2.60	0.17 ±0.01
Clarias gariepinus		Parameters				
	Season	Moisture	Protein	Lipid	Ash	GSI ± S.E
Female	Winter	75.75	17.71	3.68	2.85	1.15 ±0.11
	Spring	77.98	16.49	3.19	2.34	1.84 ±0.21
	Summer	76.25	17.55	3.67	2.53	2.18 ±0.20
	Autumn	74.81	17.92	4.37	2.90	0.48 ±0.03
Male	Winter	73.87	18.77	3.85	3.12	0.10±0.04
	Spring	74.81	17.73	3.07	2.63	0.29 ±0.05
	Summer	74.13	17.91	3.42	2.52	0.27 ±0.04
	Autumn	74.24	17.85	4.15	2.97	0.08 ±0.01

Table 4. Correlation between parameters related to proximate analysis and the seasonal mean values of GSI of *Oreochromis niloticus* and *Clarias gariepinus* in Burullus Wetland, Egypt

	Oreochromis niloticus							*Clarias gariepinus*					
Female	*Parameter*	*Moisture*	*Protein*	*Lipid*	*Ash*	*GSI*	Female	*Parameter*	*Moisture*	*Protein*	*Lipid*	*Ash*	*GSI*
	Moisture	1						Moisture	1				
	Protein	-0.925	1					Protein	-0.974	1			
	Lipid	-0.992	0.939	1				Lipid	-0.948	0.865	1		
	Ash	-0.780	0.958	0.801	1			Ash	-0.936	0.895	0.840	1	
	GSI	0.923	-0.940	-0.963	-0.839	1		GSI	0.733	-0.581	-0.779	-0.8481	1
Male	*Parameter*	*Moisture*	*Protein*	*Lipid*	*Ash*	*GSI*	Male	*Parameter*	*Moisture*	*Protein*	*Lipid*	*Ash*	*GSI*
	Moisture	1						Moisture	1				
	Protein	-0.999	1					Protein	-0.762	1			
	Lipid	-0.719	0.710	1				Lipid	-0.670	0.389	1		
	Ash	-0.931	0.943	0.803	1			Ash	-0.552	0.726	0.776	1	
	GSI	0.828	-0.825	-0.981	-0.903	1		GSI	0.629	-0.571	-0.944	-0.940	1

DISCUSSION

Biological studies are a basic requirement in fisheries science. It explains various aspects and provides answers that have a positive impact, whether in production, protection, or sustainability of resources **(James, 1973)**.

In the current study, the authors attempted to address a general observation that the characteristics of muscle tissue change seasonally for many species and to what extent the reproductive activity is related to these changes. This phenomenon may be the subject of questions and research for specialists, as well as for the consumer or even the factory that relies on fish as a raw material for supplying fillets or crude oil.

The Nile tilapia and African catfish are the mainstay of Burullus Wetland's production, constituting about 60.6 and 3.1% of the total catch, respectively **(LFRPDA, 2021)**. The given species are the most popular for local consumption, characterized by their abundance and reasonable price.

Explaining the distribution of length classes of the studied species is an axiom in biological studies that explains an important aspect of community characteristics related to size range and dominance **(James, 1973)**. Concerning the given species in Burullus Wetland, *Oreochromis niloticus* was observed with a range of 8.0-25.0cm of total length, compared to the wider range of 17.0-51.0cm that was observed for *Clarias gariepinus*. Sub-medium sizes were clarified with advanced ranking in the Nile tilapia, while the fluctuating distribution is prevalent for the African catfish, with a non-significant numerical abundance for the large size groups. The work of **El-Bokhty *et al*. (2013)** clarified a coincided range, 8.5-26.5cm, for *Oreochromis niloticus* in Burullus Wetland, while a more limited range, 19.2-29.7cm, was observed for *Clarias gariepinus* in the same site **(El-Shaer & Alabssawy, 2019)**. The differences in the sizes obtained, as well as the frequency of the length classes, actually differed depending on the fishing gear and may be due to the method of taking the sub-sample **(FAO, 2005; El-Bokhty *et al*., 2013)**.

Gonadosomatic index (GSI) is a fundamental biometric parameter and is considered a highly reliable indicator of reproductive activity although its values vary according to the species and reproductive strategy **(Rizzo & Bazzoli, 2019)**.

The intensity spawning season for *Oreochromis niloticus* was detected in summer, as both sexes coincided to peak during the specific season. For *Clarias gariepinus*, males were found to peak first during the spring and maintained a relatively high GSI value during the summer until the females achieved it, which is an evidence on the occurence of spawning. The findings of the present study align with the work of **El-Betar (2009)**, who also observed that *Oreochromis niloticus* in Burullus Wetland exhibited two peaks of activity during the summer months. This suggests a seasonal pattern in the behavior or physiology of *O. niloticus*, likely related to environmental conditions or reproductive cycles. A coincided breeding of *Clarias gariepinus* was obtained during the period from April to July in Lake Tana, Ethiopia **(Ameha *et al*., 2006)** and from March to June in Lake Chamo, Ethiopia **(Dadebo *et al*., 2011)**. Moreover, **El-Zoghby *et al*. (2010)** reported a closed result with a confirmed spawning season extending from spring to summer. Compared to some other studies, the low mean values of GSI reported in the present study for *Clarias gariepinus* may be due to the method used for calculation where the total body weight was used; moreover, differences in food availability, stomach fullness and environmental suitability may lead to a high percentage of total body weight versus gonads **(Wubie *et al*., 2023)**.

Maturity stages of gonads were identified according to **Gokhale (1957)** with some modifications to be more suitable for the studied species. Concerning *Oreochromis niloticus*, male and female followed the same pattern in the seasonal distribution of maturity stages. During winter, gonads with advanced maturation (ripe and spawning) were represented with the lowest mean value, which is consistent with achieving the minimum value of GSI, expressing the rest season. The percentage of advanced stages increases gradually by spring and reaches a maximum during summer, coinciding with peaked GSI, which is a period of intense reproductive activity. By fall season, the average mean value of the GSI gradually decreases with the highest percentage of spent gonads, expressing the post-spawning period. The sequences shown suggest that *Oreochromis niloticus* in Burullus Wetland has prolonged reproductive activity, with the exception of winter, that extends throughout the rest of the seasons. Identical results were demonstrated by **El-Betar (2009)** for the same species in Burullus Wetland, in terms of the percentage distribution of advanced stages and the extension of reproductive activity for most seasons of the year. **Peterson *et al*. (2004)** reported that the distribution of maturity stages against the GSI values of *Oreochromis niloticus* in Coastal Mississippi Watersheds indicated a year-round reproduction with increased spawning intensity in spring (March to May) and during late summer (August to September).

The results indicated that males and females of *Clarias gariepinus* were compatible in strategy and pattern of sexual development, although the males preceeded the females and peaked in the spring. Gonads with advanced maturity stages prevailed during the spring and summer seasons, supported by the highest mean values of GSI. It is an extended period of reproductive activity, while fall is the post-spawning season and winter is the resting season. Almost close results were reported by **El-Zoghby *et al*. (2010)**, **Dadebo *et al*. (2011)** and **Ragheb (2016)**.

Concerning the proximate composition of the muscle tissue, the overall mean values of *Oreochromis niloticus* were 78.28, 16.38, 2.40 and 2.41% for moisture, protein, lipid and ash, respectively. Asymptotic values were observed for the same species in Lake Oyan, Nigeria **(Olopade *et al*., 2016)**, as well as in 3 water bodies in Zimbabwe **(Jim *et al*., 2017)**. The mentioned components were 75.23, 17.74, 3.67 and 2.73% for *Clarias gariepinus*, respectively. **Osibona *et al.* (2006)** and **Adetuyi *et al*. (2012)** reported coincident values for the given species in Nigeria.

The Nile tilapia and African catfish showed a highly significant positive correlation between GSI values and moisture content in the muscles, while the correlation was highly negative with the rest of the components. The same response was observed gradually toward the advanced maturity stages. It is noted that the changes were more severe in the Nile tilapia than in the African catfish, and in females more severe than in males.

Concerning lipids, including triglycerides, they are an essential source of energy and vital metabolic processes in fish **(Ghaedi *et al*., 2016)**. It provides the energy required for gonadogenesis and embryogenesis, in addition to its crucial role in the structure of the cell and its organelles **(Agh *et al*., 2020)**. Lipids are stored in the muscles and liver and are mobilized to the gonads in the gametogenesis stage, as pre-stored lipids are an essential resource, and the decrease in muscle lipid is a natural adaptation of tissues according to the needs and priorities of vital processes **(Migaud *et al*., 2013; Mustafa *et al*., 2020)**. Lipid utilization during reproduction is explained in Fig. (8).

Regarding the depletion in protein levels, protein is a major reliable source in the structural composition of cells, as well as a source of vital energy, and its levels are subject to change according to the level of biological activity needs **(Cho *et al*., 2023)**. Protein is the basic element of cellular structure and is absolutely relied upon during gonad development and gametogenesis. It contributes strongly to very complex biological processes, including vitellogenesis, the process of yolk protein synthesis in the liver and mobilized into the oocyte, and zonagenesis, the synthesis of eggshell zona radiata proteins **(Arukwe & Goksøyr, 2003)**. Protein is a vital resource for almost biological activates; its mean values in the muscle tissue were found to be negatively correlated with the gonadal maturation of *Bagrus bajad* in Burullus Wetland **(El-Betar, 2017)**.

Minerals are inorganic components necessary to complete most vital processes. They can be divided into macro-elements, which the body needs in large quantities and are essential for the synthesis of hard tissues such as bones and scales, and micro-elements, which are involved in the synthesis of enzymes and hormones **(Volkoff & London, 2018)**. Macro-elements (phosphorus and calcium) appear important for inducing fecundity, hatchability and reducing deformities, also micro-elements has a significant negative effect on the efficiency of gametogenesis in cases of severe deficiency for a long period **(Izquierdo *et al*., 2001)**. Ash is a component attributed to proximate composition. Its mean values in muscle tissue varied throughout the year. Reproductive activity and food availability may be the main determining factors **(El-Betar, 2017)**.

Whereas females seem to invest energy in gametogenesis, in several species, the courtship of the female by the male is a complex and energetically costly behavior, as it involves swimming and fighting. Although most oviparous fish leave their eggs after spawning, some species invest energy in parental care, by preparing nests and guarding the eggs, or stop feeding while carrying eggs in their mouth, while other species feed during spawning using energy throughout a prolonged spawning season **(Volkoff & London, 2018)**.

CONCLUSION

The Nile tilapia and the African catfish are widely distributed species. The current study showed that they have an extended breeding season. Summer is the period of intense breeding for the Nile tilapia, while winter is the post-breeding and resting season. The African catfish's gonads are active during spring and reach intense breeding during the summer season, recording a post-breeding period in fall and a resting season in winter. The current study proved that the proximal components of muscle tissue were significantly correlated with gonad development. The correlation was negative and highly significant for all components, except for moisture content, which had a positive correlation.

Ethical Statements

This study does not need any formal approval, as no live fish were used in an experimental form. The study area is not restricted to fishing activities and is not subject to species protection in any way. The species is designated as ‘least concern’ by IUCN’s Red List of threatened species. We have not violated the directives of the NIOF Committee for Ethical Care of Marine Organisms and Experimental Animals, Egypt (NIOF- IACUC) in any way.

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Conflict of interest

The authors declare that they have no competing financial interests or personal relationships that could influence the study results in any way.

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