The effects of diet and temperature on enzymes, hormones, and fecundity of the African Catfish *Clarias gariepinus* (Burchell 1822)

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**ABSTRACT**

The aim of this study was to check the effect of multiple temperatures and various protein diet formulas on liver enzymes, gonadotropins, and growth hormone (GH) using African catfish *Clarias gariepinus*. *C. gariepinus* was exposed to multiple temperatures \(T_{28}^\circ C\), \(T_{32}^\circ C\), and \(T_{24}^\circ C\) and various protein diet formulas: \(D_1\) (fishmeal-based diet), \(D_2\) (soymeal-based diet), and \(D_3\) (pea-meal based diet). Tilapia commercial feed \(D_4\) was used as reference diet. A total of 720 individuals with an average weight (101–104 g) were stocked at a density of 20 individual fish per tank in 12 tanks of three replicates. Liver enzymes, gonadotropins, GH, and fish fecundity were measured after 16 weeks. The results revealed that liver enzyme like glutamate-oxaloacetate transaminase was significantly \((P < 0.05)\) lowered at \(T_{28}^\circ C\): \(D_1\) diet, while glutamic pyruvic acid transaminase was lowered by \(T_{28}^\circ C\): \(D_3\) diet. However, no effect was observed on creatinine \((P > 0.05)\) at any experimental condition. Follicle-stimulating hormone and luteinizing hormone were significantly \((P < 0.05)\) increased at \(T_{28}^\circ C\): \(D_1\) diet and \(T_{28}^\circ C\): \(D_3\) diet, respectively. GH was significantly \((P < 0.05)\) increased by \(T_{28}^\circ C\): \(D_3\). The relative weight of the ovary of *C. gariepinus* was significantly \((P < 0.05)\) increase at \(T_{28}^\circ C\): \(D_1\), while the testsis relative weight was increased with \(T_{28}^\circ C\): \(D_3\). The result from this study revealed that there is a direct relationship of temperature on fish fecundity, enzymes, and reproductive hormones in *C. gariepinus*. The temperature of 28°C along with fishmeal or soy-meal positively improved the fecundity and health of fish.

1. **INTRODUCTION**

*Clarias gariepinus* (the African catfish) is an important cultured fish in the tropical and subtropical areas [1]. *C. gariepinus* is a well-known fish for fast growth rate and resistance to adverse conditions such as handling, temperature fluctuation, low oxygen, deteriorated water quality, and high stocking density [2]. The aquaculture of African catfish expanded greatly in the 1970s and 1980s [3,4]. The aquaculture of *C. gariepinus* is suitable in developed and developing countries both biologically and economically [5].

Various fish diets were tested by researchers in the past to optimize the growth of fish without affecting the health of fish [6]. The fluctuation in temperature and nutrition could induce the stress which, in turn, could affect the fish in aquaculture system [7,8]. Optimum water temperature allows fish to grow faster and healthier. Water temperature and fish feeding rate are the most important factors that affect the growth of fish [9]. The fish metabolic rate is significantly affected by water temperature. The decrease in water temperature increases the activity of tissue enzyme [10,11]. Growth hormone (GH) would also influence by changing environmental conditions [12,13], fish nutrition [14], and feed ingredients [15].

Pituitary gonadotropins, follicle-stimulating hormone (FSH), and luteinizing hormone (LH) play a central role in regulating gametogenesis and gonadal hormones production which are required for the development of sexual behavior and secondary sex characters in all vertebrates [16,17]. Early developmental stages of the gonads such as vitellogenesis and spermatogenesis are stimulated by FSH, while later stages such as ovulation and spermiation are stimulated by LH [18].

Fish fecundity is an important tool of fishery biology; it has a direct effect on fish stock recruitment and management as well as fish production. Fish fecundity is defined as the number of eggs just before spawning [19].

In the present study, we have investigated the response of liver enzyme, reproductive parameters, GH, and fecundity of the fish by four different types of diets comprising of altered protein source at three different temperature conditions using African catfish *C. gariepinus*.

2. **MATERIALS AND METHODS**

2.1. **Experimental Fish**

African catfish *C. gariepinus* was obtained from the King Abdul Aziz City of Science and Technology research station. 720 fish with an...
average weight between 101 and 104 g were randomly selected and
stocked in 12 tanks with three replicates at a density of six males and
seven females per tank at Zoology Department, King Saud University,
Kingdom of Saudi Arabia. 2 weeks before the start of the feeding
trials, a commercial feed containing 36% crude protein was fed to fish
twice a day at 2% of fish weight.

2.2. Fish Feed Formulation
The following feed having 36% crude protein was: Diet 1 (D1) the
control was formulated of fishmeal, wheat, vitamin, and mineral
premix, and fat. Fishmeal was partially replaced with soybean meal
in diet 2 (D2) and Pea-meal in diet 3 (D3), while D4 was ARASCO
commercial diet (36% crude protein) is used as a reference. Fish were
fed 3% per body weight 3 times on a daily basis.

2.3. Water Quality
Water quality parameters such as temperature, pH, dissolved oxygen,
ammonia, nitrite, and nitrate were monitored weekly throughout
the study. The temperature was measured using a mercury-in-glass
thermometer, while the dissolved oxygen and pH were measured using
a dissolved oxygen meter HANNA-H9142 model and HANNA-
H98107 model, respectively. Water temperature (T28, T30, and T32) was
controlled by heaters at three different levels for each diet as (T28, T30,
and T32 °C), respectively.

2.4. Enzymes and Hormones
Blood was drawn from arterial caudalis with heparinized syringes
to measure the level of glutamic pyruvic acid transaminase (GPT),
glutamic oxaloacetic acid transaminase (GOT), and creatinine
following the method as described previously [20]. LH, FSH, and GH
were measured using blood serum using a commercial kit of enzyme
immunoassay.

2.5. Sperm Morphometry
The abdominal cavity of each fish from different treatments was
dissected and testes were removed and prepared for scanning electron
microscopy using JSM-6380 LA scanning electron microscope by
following the methods as described previously [21] at an accelerating
evoltage of 0.3–30 kV, Appendix V. The length and width of the sperm
head, mid-piece, and tail were measured and recorded [Figure 1].

2.6. Fish and Gonadal Measurements
The weight of each fish (C. gariepinus) was measured with a digital
balance at the start and end of the experiment. The length of each fish
was measured before the beginning and at the end of the experiment
using a ruler. The results were recorded. The ovaries and testes were
removed from all of 120 individual fish from experimental and control
group, and their relative weights were recorded.

2.7. Fecundity Determination
Fish fecundity was quantified by taking three samples of ovaries
weighing 1 g each from each experimental and control group. The
anterior, middle, and posterior regions of both ovaries from each fish
were used to collect ovaries subsamples as described [22]. The
subsamples were spread evenly on a counting slide with a few drops
of water, and the number of mature ova was counted, and the average
number of three areas was used to determine the fecundity using
following formula.

\[
\text{Fish fecundity} = \frac{\text{Number of ova in the subsample} \times \text{total ovary weight}}{\text{Weight of subsample}}
\]

Eggs within each subsample were counted for both ovaries, and the
mean number of eggs was used to calculate a number of eggs per gram
of fish [23]. The fecundity of C. gariepinus related to fish weight and
fish length was also measured.

2.8. Statistical Analysis
All values were recorded as a mean ± standard deviation and subjected
to two-way analysis of variance using 95% confidence level to test for
significant differences between the various treatment means obtained
for enzymes and hormones as described previously [24], using SPSS
10 for window software package. Regression analysis was used to
measure the relationship between fecundity variables. The linear
correlation coefficient (r) and the coefficient of determination (r²) were
calculated to evaluate the fit of the linear function to the imperial data.
The significance of correlation coefficients for chosen relationships
among the traits was subjected to the t-test [25].

3. RESULTS AND DISCUSSION

3.1. Glutamate-oxaloacetate Transaminase, Glutamic-pyruvic
Transaminase, and Creatinine
The difference in concentration of GOT in C. gariepinus was
statistically significant (P < 0.05) when the fish are exposed to
various temperature levels and different diets. As shown in Table 1,
the maximum concentrations of GOT were attained at T32, and D4, as
129.8 µ/l and lowest at T28 and D1, as 60.55 µ/l, respectively. Similarly,
the concentration of GPT in C. gariepinus males and females was
significantly different (P < 0.05), even though exposing them to the
same treatments. The highest concentration of GPT was recorded
as 64.5 µ/l at T30 and D1 and the lowest was 36.95 µ/l which was
recorded at T28, D1, and T30, D1, respectively (Table 2). Surprisingly, the temperature or the
diet alone has not affected the blood creatinine level significantly
between control and treated fish; however, a significant difference
(P < 0.05) was noted in blood creatinine level as a combined effect
of temperature and diet. The maximum blood creatinine was recorded
as 0.45 ± 0.05 mg at two experimental conditions (i) at T32, D2, and
(ii) at T32, D3. On the other side, the lowest value of blood creatinine
was 0.317 ± 0.04 mg, which was observed at T28, D1, and T32, D2,
respectively, experimental conditions as shown in Table 3.

Quantification of various enzymes in an animal system is essential
to gauge any change in the metabolic functions or predicting any
pathological changes in tissues or organs [26]. Water temperature has a
considerable effect on fish metabolism. The fluctuation from the optimum level changes the concentration of GOT and GPT
which has induced a negative impact on the metabolic functions of
C. gariepinus. The GOT and GPT enzymes are also biological
markers to indicate pollutant toxicity [27]. Unfavorable and stressful
environmental conditions increase GOT and GPT levels in the fish
blood. It has been previously shown that the concentration of GOT
and GPT increases in response to damages at the cellular level [28].

The water temperature which is lower than the optimal level could
enhance the activity of tissue enzymes [10]. The fluctuation in water
temperature from 27°C to 35°C promoted the change in tissue enzymes

The optimal concentrations of GOT and GPT were observed at 28°C,
while higher concentrations were recorded at 24°C and 32°C in this
study. The optimal production of these enzymes at 28°C indicates that the physiological status of *C. gariepinus* was at best at 28°C, while other temperatures induced a negative effect on the growth.

### 3.2. Sex and GH

The concentrations of LH in *C. gariepinus* were significantly different (*P* < 0.05) at different temperatures, diets, and their combinations. The highest concentration of LH was 0.854 ± 0.03 μ/l which was recorded at experimental conditions of T<sub>3</sub> and D<sub>1</sub> and the concentration was lowest at the experimental condition of T<sub>24</sub> and D<sub>1</sub>, which was 0.431 ± 0.03 μ/l [Table 4]. The variability in temperature and diet also induced a significant difference in FSH concentration in *C. gariepinus*. As shown in Table 5, the highest value of FSH was 0.789 ± 0.01 μ/l at the experimental condition of T<sub>1</sub> and D<sub>1</sub> and the lowest was 0.566 ± 0.02 μ/l at T<sub>13</sub> and D<sub>1</sub>. Similarly, the GH in *C. gariepinus* males and females also showed a significant difference (*P* < 0.05) at various temperatures, diets, and the combination of diets and temperature. The highest concentration was found to be 0.905 ng/ml at T<sub>28</sub> and D<sub>4</sub>, and the lowest value was 0.744 ng/ml at T<sub>12</sub> and D<sub>4</sub> [Table 6].

Measurements of FSH and LH in *C. gariepinus* are reported to show some disruption in their activity when exerted to a sublethal concentration of 4-nonylphenol [29]. The reproductive activity of fish is regulated by the brain–pituitary–gonad axis. The vitellogenesis in female fish is regulated by FSH while; oocyte maturation is accomplished by LH [17]. In the present study, sex hormones were negatively affected

### Table 1: Concentration of GOT μ/l in *C. gariepinus* males and females treated with different diets and temperatures at the end of the experiment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>D&lt;sub&gt;1&lt;/sub&gt;</th>
<th>D&lt;sub&gt;2&lt;/sub&gt;</th>
<th>D&lt;sub&gt;3&lt;/sub&gt;</th>
<th>D&lt;sub&gt;4&lt;/sub&gt;</th>
<th>Overall mean</th>
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<tbody>
<tr>
<td>Temperature</td>
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<td></td>
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<tr>
<td>T&lt;sub&gt;1&lt;/sub&gt;</td>
<td>62.72±3.03</td>
<td>93.23±1.82</td>
<td>109±1.81</td>
<td>62.26±1.48</td>
<td>81.97±20.0</td>
</tr>
<tr>
<td>T&lt;sub&gt;2&lt;/sub&gt;</td>
<td>82.82±1.6</td>
<td>60.55±1.28</td>
<td>87.47±2.76</td>
<td>77.67±2.08</td>
<td>77.13±10.6</td>
</tr>
<tr>
<td>T&lt;sub&gt;3&lt;/sub&gt;</td>
<td>110.5±2.15</td>
<td>112.4±2.15</td>
<td>128.1±17</td>
<td>129.8±1.71</td>
<td>120.2±12.1</td>
</tr>
<tr>
<td>Overall mean</td>
<td>83.3±20.3</td>
<td>88.73±22.1</td>
<td>108±19.5</td>
<td>89±29.9</td>
<td>93.0±24.5</td>
</tr>
</tbody>
</table>

D<sub>1</sub>, D<sub>2</sub>, D<sub>3</sub>, and D<sub>4</sub> referred to different diets, and T<sub>1</sub>, T<sub>2</sub>, and T<sub>3</sub> referred to temperatures T<sub>24</sub>°C, T<sub>13</sub>°C, and T<sub>12</sub>°C that used for the experiment, respectively.

### Table 2: Concentration of GPT μ/l in *C. gariepinus* males and females treated with different diets and temperatures at the end of the experiment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>D&lt;sub&gt;1&lt;/sub&gt;</th>
<th>D&lt;sub&gt;2&lt;/sub&gt;</th>
<th>D&lt;sub&gt;3&lt;/sub&gt;</th>
<th>D&lt;sub&gt;4&lt;/sub&gt;</th>
<th>Overall mean</th>
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<tr>
<td>Temperature</td>
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</tr>
<tr>
<td>T&lt;sub&gt;1&lt;/sub&gt;</td>
<td>51.78±1.62</td>
<td>55.2±1.39</td>
<td>50.35±1.34</td>
<td>64.5±1.28</td>
<td>55.46±5.78</td>
</tr>
<tr>
<td>T&lt;sub&gt;2&lt;/sub&gt;</td>
<td>42.3±2.16</td>
<td>52.03±4.49</td>
<td>53.93±1.16</td>
<td>36.95±1.72</td>
<td>46.3±7.55</td>
</tr>
<tr>
<td>T&lt;sub&gt;3&lt;/sub&gt;</td>
<td>47.9±1.24</td>
<td>42.2±1.54</td>
<td>37.98±1.72</td>
<td>42.33±1.1</td>
<td>42.6±3.83</td>
</tr>
<tr>
<td>Overall mean</td>
<td>47.33±4.32</td>
<td>49.81±6.29</td>
<td>47.42±7.16</td>
<td>47.93±12.3</td>
<td>48.12±7.98</td>
</tr>
</tbody>
</table>

D<sub>1</sub>, D<sub>2</sub>, D<sub>3</sub>, and D<sub>4</sub> referred to different diets, and T<sub>1</sub>, T<sub>2</sub>, and T<sub>3</sub> referred to temperatures T<sub>24</sub>°C, T<sub>13</sub>°C, and T<sub>12</sub>°C that used for the experiment, respectively.

### Table 3: Concentration of Creatinine mg/dl in *C. gariepinus* males and females treated with different diets and temperatures at the end of the experiment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>D&lt;sub&gt;1&lt;/sub&gt;</th>
<th>D&lt;sub&gt;2&lt;/sub&gt;</th>
<th>D&lt;sub&gt;3&lt;/sub&gt;</th>
<th>D&lt;sub&gt;4&lt;/sub&gt;</th>
<th>Overall mean</th>
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<tr>
<td>Temperature</td>
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<td></td>
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<tr>
<td>T&lt;sub&gt;1&lt;/sub&gt;</td>
<td>0.41±0.04</td>
<td>0.43±0.05</td>
<td>0.35±0.05</td>
<td>0.45±0.05</td>
<td>0.413±0.06</td>
</tr>
<tr>
<td>T&lt;sub&gt;2&lt;/sub&gt;</td>
<td>0.43±0.05</td>
<td>0.31±0.04</td>
<td>0.41±0.04</td>
<td>0.417±0.04</td>
<td>0.396±0.06</td>
</tr>
<tr>
<td>T&lt;sub&gt;3&lt;/sub&gt;</td>
<td>0.31±0.04</td>
<td>0.43±0.05</td>
<td>0.45±0.05</td>
<td>0.4±0.06</td>
<td>0.4±0.07</td>
</tr>
<tr>
<td>Overall mean</td>
<td>0.389±0.07</td>
<td>0.394±0.07</td>
<td>0.406±0.06</td>
<td>0.422±0.05</td>
<td>0.403±0.06</td>
</tr>
</tbody>
</table>

D<sub>1</sub>, D<sub>2</sub>, D<sub>3</sub>, and D<sub>4</sub> referred to different diets, and T<sub>1</sub>, T<sub>2</sub>, and T<sub>3</sub> referred to temperatures T<sub>24</sub>°C, T<sub>13</sub>°C, and T<sub>12</sub>°C that used for the experiment, respectively.

### Table 4: Concentration of LH μ/l in female *C. gariepinus*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>D&lt;sub&gt;1&lt;/sub&gt;</th>
<th>D&lt;sub&gt;2&lt;/sub&gt;</th>
<th>D&lt;sub&gt;3&lt;/sub&gt;</th>
<th>D&lt;sub&gt;4&lt;/sub&gt;</th>
<th>Overall mean</th>
</tr>
</thead>
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<tr>
<td>Temperature</td>
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<td></td>
</tr>
<tr>
<td>T&lt;sub&gt;1&lt;/sub&gt;</td>
<td>0.46±0.13</td>
<td>0.43±0.03</td>
<td>0.437±0.06</td>
<td>0.546±0.03</td>
<td>0.468±0.08</td>
</tr>
<tr>
<td>T&lt;sub&gt;2&lt;/sub&gt;</td>
<td>0.437±0.09</td>
<td>0.52±0.06</td>
<td>0.587±0.05</td>
<td>0.57±0.03</td>
<td>0.53±0.08</td>
</tr>
<tr>
<td>T&lt;sub&gt;3&lt;/sub&gt;</td>
<td>0.854±0.03</td>
<td>0.807±0.07</td>
<td>0.619±0.03</td>
<td>0.763±0.08</td>
<td>0.76±0.1</td>
</tr>
<tr>
<td>Overall mean</td>
<td>0.584±0.22</td>
<td>0.589±0.17</td>
<td>0.547±0.09</td>
<td>0.626±0.11</td>
<td>0.587±0.16</td>
</tr>
</tbody>
</table>

D<sub>1</sub>, D<sub>2</sub>, D<sub>3</sub>, and D<sub>4</sub> referred to different diets, and T<sub>1</sub>, T<sub>2</sub>, and T<sub>3</sub> referred to temperatures T<sub>24</sub>°C, T<sub>13</sub>°C, and T<sub>12</sub>°C that used for the experiment, respectively.
by temperature and diet. The concentration of LH positively increased with temperature from 24°C to 32°C. The highest concentration of LH was recorded in C. gariepinus with fishmeal-based diet ($D_1$) while soybean meal-based diet ($D_3$) reduced the concentration of LH in this study. The concentration of FSH reached at its maximum at 28°C then decreased with increasing temperature up to 32°C. The FSH and LH are important for better egg quality and successful fish reproduction. The fishmeal-based diet ($D_1$) produced the highest concentration of FSH while pea-meal based diet ($D_4$) produced the lowest concentration of FSH in this study. Water temperature regulates the level of GH. The best temperature for optimum production of GH in C. gariepinus was found to be 28°C in this study. The level of hormones increased from 24°C to 28°C then decreased at a higher temperature. Fish diet also has an essential role in GH regulation. It was observed in this study that fishmeal-based diet ($D_1$) increases the concentration of GH and pea-meal based diet reduces the concentration of GH in C. gariepinus.

### 3.3. Sperm Morphometrics and Gonadal Weight

The effect of different diets and temperature and temperate and diet combinations on the sperm head, mid-piece, and tail of sperm of male fish of C. gariepinus is shown in Table 7. The sperm head length showed significant ($P < 0.05$) difference between variable diets and temperature and to different diet and temperature combinations. The highest length which was recorded was 2.348 ± 0.9 µm at $T_{24}$ and $D_1$ and the lowest length was 1.395 ± 0.2 µm at $T_{32}$ and $D_2$, respectively. The maximum length (2.348 ± 0.9 µm) of sperm head was found at the experimental condition of $D_1$ and $T_1$ while the minimum length (1.18 ± 0.03 µm) was found at $T_{32}$ and $D_2$. The sperm head width showed a significant difference ($P < 0.05$) to diet as well as temperature. The length of sperm mid-piece showed a significant difference between all diets, temperature, and the combined effect of diet and temperature ($P < 0.05$). The maximum and minimum values are 425.00 ± 75.20 µm and 247.75 ± 73.11 µm at $D_4$ and $T_1$, respectively. The width of sperm mid-piece was statistically not significant at any temperature or diets, but the combined effect of diet and temperature showed significant ($P < 0.05$) difference in the width in the midpiece of sperm of C. gariepinus. The maximum width of sperm midpiece was 539.44 ± 34.67 µm at $D_1$ and $T_1$ and the minimum value was 292.13 ± 5.25 µm at $T_{34}$ and $D_4$. The tail length of the sperms showed a significant difference between all diets, temperature, and their combinations. The highest and lowest values are 41.95 ± 6.99 µm and 9.09 ± 5.2 µm at $T_{34}$ and $D_1$ and $T_{43}$ and $D_4$, respectively. On the other hand, the width of the sperm tail was significantly different for diet and their combined effect ($P < 0.05$), but the temperature showed no significant difference on sperm tail length at $P < 0.05$. The highest and lowest values are 155.75 ± 38.24 µm at $T_1$ and $D_4$ and $T_{32}$ and $D_2$, respectively. Sperm length determined the speed of the sperm which is important in fertilization success; a longer flagellum means a stronger propulsive force [30,31]. Various studies showed that there is no evidence of sperm morphology on sperm quality [32]. Other studies done in Salmon indicate that there is no influence of sperm morphology on the ejaculate longevity as well as no correlation between spermatocrit and sperm morphology [33].

Various combinations of temperature and diets showed a significant ($P < 0.05$) difference in the relative weight of testis of the male C. gariepinus. The highest and lower values were 0.935% ± 0.6% and 0.282% ± 0.13% at $T_{34}$ and $D_1$ and $T_{14}$ and $D_4$, respectively, shown in Tables 8.

The result showed that treatments with both temperature and diet gave significant differences between the average relative weight of the ovary of the catfish C. gariepinus ($P < 0.05$). $D_1$ and $T_3$ showed the highest relative weight of ovary as 17.266% ± 6.89% and the lower value at $T_{34}$ and $D_2$ as 11.728% ± 5.33% as shown in Tables 9 and 10.

Unlike capture fisheries, the aquaculture involves human intervention in fish breeding to exceed the production and yield of the natural environment [34]. Temperature and diet management will improve gonadotropins and liver enzymes to achieve an effective development of fish sperms and ova to get successful egg fertilization and eventually maximize the fish number in the system. One of the most important problems of aquaculture development is the scarcity of fish fingerlings of the chosen species for culture [35]. We need to adjust temperature and diet quality to produce enough seeds for aquaculture development of the fish. This study indicates that the gonads or gonadosomatic index, quality of sperms, levels of gonadotropins, and liver enzymes

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### Table 5: Concentration of (FSH) µ/l in C. gariepinus males and females at the end of the experiment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$D_1$</th>
<th>$D_2$</th>
<th>$D_3$</th>
<th>$D_4$</th>
<th>Overall mean</th>
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<tr>
<td>Temperature</td>
<td></td>
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</tr>
<tr>
<td>$T_1$</td>
<td>0.737±0.03</td>
<td>0.7±0.04</td>
<td>0.742±0.03</td>
<td>0.75±0.03</td>
<td>0.73±0.04</td>
</tr>
<tr>
<td>$T_2$</td>
<td>0.789±0.01</td>
<td>0.759±0.04</td>
<td>0.738±0.01</td>
<td>0.71±0.03</td>
<td>0.75±0.04</td>
</tr>
<tr>
<td>$T_3$</td>
<td>0.609±0.03</td>
<td>0.57±0.02</td>
<td>0.566±0.02</td>
<td>0.59±0.04</td>
<td>0.58±0.03</td>
</tr>
<tr>
<td>Overall mean</td>
<td>0.712±0.08</td>
<td>0.676±0.09</td>
<td>0.682±0.09</td>
<td>0.68±0.08</td>
<td>0.68±0.08</td>
</tr>
</tbody>
</table>

$D_1$, $D_2$, $D_3$, and $D_4$ correspond to different diets, and $T_1$, $T_2$, and $T_3$ correspond to temperatures $T_{24}$, $T_{28}$, and $T_{32}$ °C that used for the experiment, respectively.

### Table 6: Concentration of GH ng/ml in the blood of C. gariepinus males and females at the end of the experiment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$D_1$</th>
<th>$D_2$</th>
<th>$D_3$</th>
<th>$D_4$</th>
<th>Overall mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T_1$</td>
<td>0.86±0.02</td>
<td>0.831±0.03</td>
<td>0.842±0.03</td>
<td>0.85±0.02</td>
<td>0.848±0.03</td>
</tr>
<tr>
<td>$T_2$</td>
<td>0.905±0.02</td>
<td>0.833±0.02</td>
<td>0.819±0.02</td>
<td>0.859±0.02</td>
<td>0.854±0.04</td>
</tr>
<tr>
<td>$T_3$</td>
<td>0.813±0.02</td>
<td>0.796±0.01</td>
<td>0.744±0.02</td>
<td>0.807±0.02</td>
<td>0.79±0.03</td>
</tr>
<tr>
<td>Overall mean</td>
<td>0.86±0.04</td>
<td>0.82±0.02</td>
<td>0.802±0.05</td>
<td>0.84±0.03</td>
<td>0.83±0.04</td>
</tr>
</tbody>
</table>

$D_1$, $D_2$, $D_3$, and $D_4$ correspond to different diets, and $T_1$, $T_2$, and $T_3$ correspond to temperatures $T_{24}$, $T_{28}$, and $T_{32}$ °C that used for the experiment, respectively.
showed the best performance at the temperature of 28°C and a diet of fishmeal and soy-meal. These parameters would provide the baseline to attain the best production for the aquaculture of C. gariepinus in future.

### 3.4. Fecundity

Fecundity is a very essential characteristic of fish culture because it gives an indication of the average reproductive feature of the fish [36]. The fecundity of C. gariepinus varied between 54,060 and 294,315 in this study; however, the absolute fecundity was calculated 125,178 ± 607.72 at $T_{28}$ and $D_2$ [Table 9].

The regression analysis between fish fecundity and fish weight showed a high correlation coefficient ($r^2$) between the logarithm of fecundity and weight throughout the experimentation equal to 0.861 [Figure 2].

### Table 7: Average morphometry (µm) of different parts of sperm of the C. gariepinus treated with different diets and temperature during the period of the experiment

<table>
<thead>
<tr>
<th>Diet</th>
<th>Temperature</th>
<th>Head</th>
<th>Mid-piece</th>
<th>Tail</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Length</td>
<td>Width</td>
<td>Length</td>
</tr>
<tr>
<td>$D_1$</td>
<td>$T_1$</td>
<td>1.63±0.2</td>
<td>1.225±0.04</td>
<td>306.91±96.7</td>
</tr>
<tr>
<td></td>
<td>$T_2$</td>
<td>1.88±0.5</td>
<td>1.54±0.5</td>
<td>78.55±59.41</td>
</tr>
<tr>
<td></td>
<td>$T_3$</td>
<td>2.297±0.8</td>
<td>1.865±0.79</td>
<td>258.44±72.64</td>
</tr>
<tr>
<td>Overall mean</td>
<td></td>
<td>1.94±0.6</td>
<td>1.54±0.6</td>
<td>282.77±78.1</td>
</tr>
<tr>
<td>$D_2$</td>
<td>$T_1$</td>
<td>1.457±0.1</td>
<td>1.18±0.03</td>
<td>312.72±38.82</td>
</tr>
<tr>
<td></td>
<td>$T_2$</td>
<td>1.802±0.2</td>
<td>1.249±0.3</td>
<td>359.2±128.6</td>
</tr>
<tr>
<td></td>
<td>$T_3$</td>
<td>1.395±0.1</td>
<td>1.202±0.1</td>
<td>352.9±76.34</td>
</tr>
<tr>
<td>Overall mean</td>
<td></td>
<td>1.5±0.2</td>
<td>1.20±0.1</td>
<td>338.34±83.8</td>
</tr>
<tr>
<td>$D_3$</td>
<td>$T_1$</td>
<td>1.611±0.1</td>
<td>1.223±0.1</td>
<td>366.5±50.3</td>
</tr>
<tr>
<td></td>
<td>$T_2$</td>
<td>1.735±0.2</td>
<td>1.203±0.1</td>
<td>349.5±93.71</td>
</tr>
<tr>
<td></td>
<td>$T_3$</td>
<td>1.538±0.4</td>
<td>1.324±0.4</td>
<td>372.63±98.1</td>
</tr>
<tr>
<td>Overall mean</td>
<td></td>
<td>1.63±0.3</td>
<td>1.25±0.24</td>
<td>362.88±80.4</td>
</tr>
<tr>
<td>$D_4$</td>
<td>$T_1$</td>
<td>1.613±0.2</td>
<td>1.2±0.04</td>
<td>247.75±73.11</td>
</tr>
<tr>
<td></td>
<td>$T_2$</td>
<td>1.931±0.7</td>
<td>1.526±0.5</td>
<td>280±69.9</td>
</tr>
<tr>
<td></td>
<td>$T_3$</td>
<td>2.348±0.9</td>
<td>2.102±1</td>
<td>452±75.2</td>
</tr>
<tr>
<td>Overall mean</td>
<td></td>
<td>2.027±0.8</td>
<td>1.69±0.8</td>
<td>334±116</td>
</tr>
</tbody>
</table>

$D_1$, $D_2$, $D_3$, and $D_4$ referred to different diets, and $T_1$, $T_2$, and $T_3$ referred to temperatures $T_{24}°C$, $T_{28}°C$, and $T_{32}°C$ that used for the experiment, respectively.

### Table 8: Average testis/body weight % of African Catfish C. gariepinus

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$D_1$</th>
<th>$D_2$</th>
<th>$D_3$</th>
<th>$D_4$</th>
<th>Overall mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T_1$</td>
<td>0.678±0.21</td>
<td>0.68±0.3</td>
<td>0.935±0.6</td>
<td>0.935±0.19</td>
<td>0.807±0.37</td>
</tr>
<tr>
<td>$T_2$</td>
<td>0.834±0.24</td>
<td>0.68±0.29</td>
<td>0.615±0.25</td>
<td>0.787±0.22</td>
<td>0.729±0.26</td>
</tr>
<tr>
<td>$T_3$</td>
<td>0.45±0.2</td>
<td>0.73±0.29</td>
<td>0.76±0.17</td>
<td>0.282±0.13</td>
<td>0.561±0.28</td>
</tr>
<tr>
<td>Overall mean</td>
<td>0.654±0.26</td>
<td>0.697±0.29</td>
<td>0.77±0.4</td>
<td>0.679±0.33</td>
<td>0.7±0.32</td>
</tr>
</tbody>
</table>

$D_1$, $D_2$, $D_3$, and $D_4$ referred to different diets, and $T_1$, $T_2$, and $T_3$ referred to temperatures $T_{24}°C$, $T_{28}°C$, and $T_{32}°C$ that used for the experiment, respectively.

### Table 9: Absolute and relative fecundity of C. gariepinus

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Length of fish (cm)</th>
<th>Weight of fish (g)</th>
<th>Absolute fecundity</th>
<th>Relative weight of testis (%)</th>
<th>Relative weight of ovary (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>27.80±2.06–34.00±1.23</td>
<td>169.20±8.12–277.85±11.31</td>
<td>54,060±489.06–294,315±1,987.63</td>
<td>0.935±0.60–0.282±0.13</td>
<td>11.728±5.33–14.684±5.33</td>
</tr>
<tr>
<td>Mean</td>
<td>31.13±3.97</td>
<td>217.51±10.98</td>
<td>125,178±607.72</td>
<td>0.7±0.32</td>
<td>14.684±5.33</td>
</tr>
</tbody>
</table>

cm: Centimeter, g: Gram

Figures and tables are included to support the text, providing detailed data and measurements related to the study on C. gariepinus.
The correlation coefficient ($r^2$) for the regression of logarithm of fecundity and total length also showed a similar result for C. gariepinus throughout the experimentation period with $r^2 = 0.708$ [Figure 3].

The total fecundity of fish is the total number of eggs of fish ovaries, while the relative fecundity is the amount of ovary egg per gram. Fish fecundity and egg qualities are important factors for fish breeding and the success of aquaculture. The present study revealed a high correlation between the logarithm of total fecundity and logarithm of both weight and length of the C. gariepinus with $R^2$ always >0.70, which mean that fecundity of C. gariepinus increased with weight and length of the fish. Similar kind of findings has also been reported in previous studies [35,37-39].

### 4. CONCLUSION

The effect of temperature and type of food on the growth, metabolism, and the physiological status of different species of fish has been studied previously [40-43]. The role of temperature and food type on fish growth and the performance of reproductive enzymes and hormones have been evaluated in C. gariepinus to achieve the successful aquaculture of this economically important catfish. The data in this study suggest an optimum temperate of 28°C for the best growth, fish fecundity and health of C. gariepinus. Moreover, the fishmeal and soymeal-based diets would be beneficial to attain the best growth and fecundity of this fish when combined with the optimum water temperature.

### 5. ACKNOWLEDGMENTS

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#### Table 10: Average relative weight % of ovary of African Catfish C. gariepinus at the end of experimentation period

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$D_1$</th>
<th>$D_2$</th>
<th>$D_3$</th>
<th>$D_4$</th>
<th>Overall mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T_1$</td>
<td>15.86±4.58</td>
<td>11.7--28±5.33</td>
<td>13.89±3.1</td>
<td>12.12±2.17</td>
<td>13.40±4.2</td>
</tr>
<tr>
<td>$T_2$</td>
<td>16.98±6.45</td>
<td>14.28±4</td>
<td>12.89±4.4</td>
<td>14.60±3.7</td>
<td>14.69±4.84</td>
</tr>
<tr>
<td>$T_3$</td>
<td>17.26±6.89</td>
<td>16.61±6.72</td>
<td>15.58±3.62</td>
<td>14.36±2.48</td>
<td>15.95±5.24</td>
</tr>
<tr>
<td>Overall mean</td>
<td>16.70±5.91</td>
<td>14.20±5.68</td>
<td>14.12±3.81</td>
<td>13.69±3.9</td>
<td>14.68±4.86</td>
</tr>
</tbody>
</table>

$D_1$, $D_2$, $D_3$, and $D_4$ referred to different diets, and $T_1$, $T_2$, and $T_3$ referred to temperatures $T_{28}^\circ$, $T_{28}^\circ$, and $T_{28}^\circ$ that used for the experiment, respectively.

---

**Figure 2:** The relationship between log of fecundity and log of the weight of C. gariepinus tested with different diets and temperature for 4 months. Log = logarithm; F = fish fecundity; W = fish weight

**Figure 3:** The relationship between logarithm of fecundity and total length of C gariepinus tested with different diets and temperature for 4 months. Log = logarithm; F = fish fecundity; L = fish length
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Burchell, 1822) fed coppens feed and

Bamidgeh

Oncorhynchus

Megalobrama amblycephala

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