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# COMPARATIVE GROWTH PERFORMANCE OF COMMON CARP (*Cyprinus carpio*) CULTIVATED IN DIFFERENT ALTITUDINAL TEMPERATURE GRADIENTS IN RWANDA

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## ABSTRACT
***A 120-day experiment was conducted to compare growth performance of Common Carp at three agro-ecological zones of different altitude (low, middle and high elevation) in Rwanda. Fish juveniles of average body weight and length of 30.4±2.30 g and 14.4±1.34 cm, respectively were randomly distributed and stocked at 200 fish per 100-m$^2$ pond in each experimental site. Total weight gain (TWG), daily weight gain (DWG), relative growth rate (RGR), specific growth rate (SGR), and coefficient of condition ($K_m$) were calculated during the experimental period. Data were subjected to one-way analysis of variance. Results showed that fish reared at low altitude zone showed significantly higher ($p < 0.05$) TWG, WG, RGR, and SGR compared to the middle and high-altitude groups. Nevertheless, growth of Common Carp was suitable in all three sampled agro-climatic zones of Rwanda. The DWG ranged from 1.16±0.03 g day$^{-1}$, 1.27±0.02 g day$^{-1}$, 1.62±0.02 g day$^{-1}$ and SGR ranged from 1.43±0.02 % day$^{-1}$, 1.50±0.01 % day$^{-1}$, 1.66±0.05 % day$^{-1}$ respectively for the high, middle and low altitude sites, hence the experimental carp fish had better growth performance records in these environments. The findings of this study demonstrated that Common Carp can could be cultured in all altitudinal gradients of Rwandan territory but preferably in low elevation agro-ecological zones where better growth performance has been observed.***

**Key words:** agro-ecological zones, aquaculture, cyprinids, temperature influence

## INTRODUCTION
Cultivation of Common Carp is a long and fascinating process, spanning millennia and different regions. Common Carp was introduced in the Rwandan territory for aquaculture in 1960 from Israel (Welcomme, 1988). Common Carp is now found in the upper Akagera system; lake Rweru and is common in lake Karago; a small highland lake North-East of Gisenyi (De Vos *et al.*, 2001). Common Carp were cultivated at Kigembe and Rwasave Fish Farming Stations but as of 1983 the fish species was no longer produced in the country.

In Rwanda, fish farming is still based on tilapia and African catfish without often much attention to environmental conditions such as low and high-altitude temperature that can limit the performance of these species. Aquaculture development is limited by difficult to access seed and feed of high quality, poor technical knowledge, inappropriate production systems, few reared species, very little research, and the cultivation of the two thermophilic fish species; the Nile tilapia and the African catfish without much attention to the environmental conditions. Attempts to improve low fish production were made by introducing the rearing of the African catfish without taking into accounts its thermal requirements. Moreover, the fish production sector is constrained by farmers' limited access to capital for establishing and expanding aquaculture activities. Inadequate capital was found to be was the most serious constraint (46.2%) to fish farming and possibly expansion (Omeje *et al.*, 2020). The importance of capital to fish farming cannot be overemphasised. Capital is needed to purchase land, feed, construct ponds, buy drugs etc. hence, capital is considered *sine qua non* to fish farming.

Rwanda has a temperate tropical highland climate, with lower temperatures that are typical for equatorial countries due to its high elevation (4507 m highest point and 950 m lowest point). There are temperature variations across the country; the mountainous West and North are generally cooler than the lower-lying East. The temperature varies from 28.2 °C or 82.8 °F to 15.0 °C or 59.0 °F (World Meteorological Organisation, 2015). Considering the Rwandan climate, the temperature may be suitable for the breeding of the common Carp. Zhang *et al.* (2024) reported that the optimal growth temperature for Common Carp (*Cyprinus carpio*) ranges between 25

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and 32°C, this fish species may perform better in various agro-ecological zones of the Rwandan territory than the two thermophilic species; the Nile tilapia and the African catfish respectively with optimal growth temperature 30-32 ºC (Nivelle *et al*., 2019) and 25-32 °C (Klimuk *et al*., 2024).

Despite Common Carp was introduced a long time ago into certain water bodies, there are no studies on its adaptability to the environmental and cultivation conditions. This study was carried out to locate the Rwandan agro-ecological zone that is suitable for the cultivation of the Common Carp.

## MATERIALS AND METHODS

### Study Area

This study was conducted in three agro-ecological zones: at Rukomo sector (Latitude, −1.6292° about 1° 37′ 45″ S; Longitude, 30.1031° about 30° 6′ 11″ E) in Gicumbi district 1950 m of altitude with annual average temperature 18° C, at Rwasave Fish Farm (Latitude, 2°40' S; Longitude, 29°45' E) in Gisagara district 1625 m of altitude with annual average temperature 23 °C, and at Gatunda sector (Latitude, −1.4063° about 1° 24′ 23″ S; Longitude, 30.1990° about 30° 11′ 56″ E) in Nyagatare district 1395 m of altitude with annual average temperature 25 °C (Ruticumugambi *et al*., 2024) (Figure 1).

### Positioning of Farming Sites

Farming sites were identified using a Global Positioning System (GPS) device, through which their geographical coordinates—longitude, latitude, and altitude—were recorded.

### Provenance of Carp Stock

A total of 1200 juvenile carps of average body weight and average body length of 30.4±2.30 g and 14.4±1.34 cm, respectively, were collected from the Rwasave Fish Farming and Research Station. They were transported in oxygenated tank to rearing areas in the three agro-ecological zones.

### Experimental Protocol

Prior to commencing the study, ponds measuring 100 $m^2$ each were drained, sun-dried and filled up to a depth of 80-90 cm with water from the peripheral canal. A water level was maintained weekly through addition of calculation to compensate for evaporation and seepage losses. Each pond was fertilized with organic fertilizers, cow and poultry manure at a dose of 2 kg $are^{-1}$ fortnightly.

Fish were randomly distributed and stocked at 200 fish per 100-$m^2$ pond (i.e., 2 fish per $m^2$) carried out in two replications. Thus, 400 carp juveniles were stocked in each agro-climatic zone.

Previously ponds were fertilized with cow and poultry manure, and a floating commercial pellet diet (35% protein content) was used a supplement. The diet was offered to fish twice daily at 9:00 am and 3:00 pm. The feeding rate varied in the beginning and at the end of the experiment from 5 to 3% of the biomass of fish in the pond.

### Control of Physico-chemical Parameters of Water

In situ: temperature (T ºC), dissolved oxygen (DO), pH, and turbidity were measured daily, respectively with thermometer, oxygen meter, pH meter, and turbidimeter. In the laboratory, total ammonia nitrogen (TAN), $NO_2^-$, and $NO_3^-$ were measured by titrimetric method using spectrophotometry. All these physico-chemical analyses were done by standard methods (APHA, 2017) in the laboratory of the College of Science & Technology of the University of Rwanda.

### Control of Zootechnical Parameters

### Growth parameters

The total weight gain (TWG, g), relative growth rate (RGR, %), daily weight gain (DWG, g $day^{-1}$) and the specific growth rate (SGR, % $day^{-1}$) were calculated monthly. A total of 20 fish were randomly captured and their weight measured by means of a digital electronic weighting scale (IndiaMart, capacity 10 kg). The zootechnical parameters were calculated as:

$$\text{TWG (g)} = \text{fW-iW},$$
$$\text{RGR (\%)} = (\text{fW-iW})/\text{iW}) \times 100,$$
$$\text{DWG (g day}^{-1}) = (\text{fW-iW})/\Delta t, \text{ and}$$
$$\text{SGR (\% day}^{-1}) = ((\text{lnfW-lniW})/\Delta t) \times 100;$$

where fW and iW are final and initial body weights, respectively of the fish.

### Coefficient of Condition

The weight-length relationship was calculated to characterise the growth conditions. The coefficient of condition was obtained as the ratio of weight of a fish to the cube of its total body length (Williams, 2000).

$$K_m = (W/L^3) \times 100;$$

where $W$ is the weight (g) and $L$ the total length (cm).

### Survival Rate (%)

Survival rate (SR) was calculated at the end of the 120-day study. This parameter was easily determined from the initial number of fish stocked in ponds and the number of fish harvested at the end of the study:

$$\text{SR (\%)} = (\text{fN/iN}) \times 100;$$

where fN is the final number of fish stocked, and iN is the initial number of fish stocked.

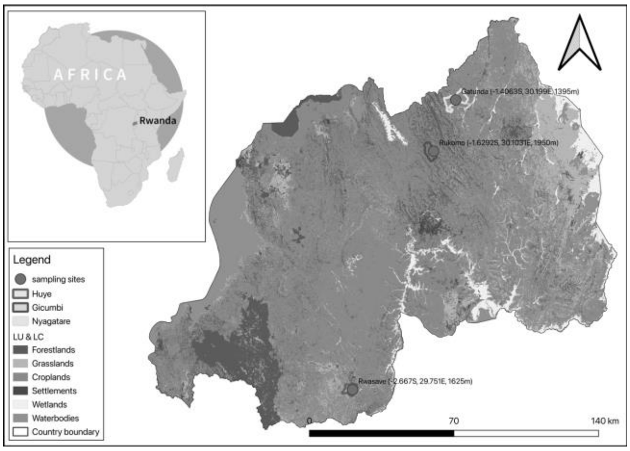


**Figure 1:** Rwandan map displaying study areas

### Feed Utilisation Parameters

Feed intake (FI), feed conversion efficiency (FCE) and feed conversion ratio (FCR) were determined to characterise feed consumption. Feed utilisation parameters were calculated as follow:

FI= dD,
FCE = (fB - iB)/dD, and
FCR = dD/ (fB - iB);

where dD is distributed diet (feed), fB is the final biomass, and iB is the initial biomass.

### Statistical Analyses

Data were analysed using the software IBM SPSS Statistics 29.0.1.0 (IBM Corp., Armonk, NY, USA). Data on the growth performance parameters, feed utilisation parameters, and physico-chemical parameters were subjected to one-way analysis of variance, and the difference between means were compared by the Tukey's range test ($p < 0.05$) to compare fish performances in the three agro-ecological zones.

## RESULTS

### Weight Gain Dynamics

The body weight progress was better at Gatunda site; a low altitude agro-ecological zone compared to the Rwasave and Rukomo sites of middle- and high-altitude agro-ecological zones, respectively. From 30.4 g of initial body weight, the juvenile fish carps reached 224, 183 and 170 g, respectively at Gatunda, Rwasave, and Rukomo sites after a duration of four months as shown in Figure 2.

### Growth Parameters

It was observed that better performance for TWG (g), DWG (g day$^{-1}$), SGR (% day$^{-1}$), and RGR (%) were recorded at the Gatunda site; a low altitude agro-climatic zone ($p < 0.05$) compared to the Rwasave and Rukomo zones, respectively of middle and high altitude. The survival rate was better at Gatunda and Rukomo sites compared to Rwasave. However, the condition did not differ for all the three experimental sites (Table 1).

### Feed Utilisation Parameters

The FCR and FCE were significantly better ($p < 0.05$) in fishes at Rwasave site compared to the Rukomo and Gatunda, while the feed intake (FI) was significantly higher ($p < 0.05$) at Gatunda site (Table 2).

### Water Quality Parameters

Temperature, dissolved oxygen (DO), and pH varied along the experimental period as shown by Figures 3, 4, and 5. Values of these physico-chemical parameters were found on the allowable range of fish rearing in aquaculture systems (Table 3).

### Optimum Range of Quality-Defining Physico-Chemical Parameters of Water

Good water quality in fish culture has to do with physico-chemical parameters with values that are within the ranges of the standard values as presented in Table 3 (Nathan and Hugh, 1977; Boyd, 1990; Wurts and Durborow, 1992; Boyd and Tucker, 1998; Zweig *et al.*, 1999; Lindholm-Lehto *et al*., 2020; Yusoff *et al*., 2024).

## DISCUSSION

### Growth and Zootechnical Parameters of Fish Reared in the Different Agro-Ecological Zones

A number of factors, such as temperature, oxygen concentration, salinity, nutrition, and photoperiod, influence the rate of growth. The rate of growth differs from species to species and sometimes it differs even within the species also, as well as being affected by many factors such as seasonality, water temperature, availability of food and oxygen, stocking density, aquaculture system, and age (Dutta, 1994; Viadero, 2005). Recent data suggested that genotypes, hormones and physiological conditions of the individual are also important endogenous regulators of growth (Dutta, 1994).

Although, the recorded temperature was found in thermal preference of Common Carp being 23-25 ºC (Boyd, 1990) at Gatunda and Rwasave sites, in the present study, Common Carp performed better at the Gatunda, the lower elevation experimental site where the temperature was recorded higher. This growth performance may be due to high temperature recorded in this site compared to the others. Indeed, high water temperatures increase the metabolic rates, resulting in increased food demand (Kausar and Salim, 2006). Water temperature significantly impacts fish

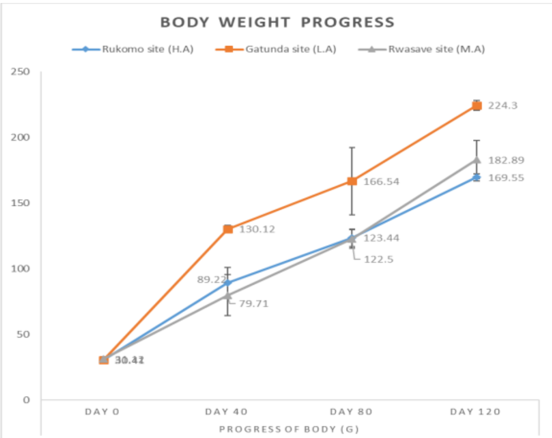


**Figure 2:** Body weight progress of carp fishes for 120-day study period in the conditions of the three agro-climatic zones of Rwanda
(HA: High Altitude, LA: Low Altitude, MA: Middle Altitude)

**Table 1:** Zootechnical parameters of Common Carp in the three agro-climatic zones

| Sites | TWG (g) | DWG (g day$^{-1}$) | SGR (% day$^{-1}$) | % RGR | % SR | $K_m$ |
|---|---|---|---|---|---|---|
| Rukomo site (HA) | 139±3.75$^b$ | 1.16±0.03$^b$ | 1.43±0.02$^b$ | 458±12.4$^b$ | 96.5±2.12$^a$ | 1.41±0.05$^a$ |
| Gatunda site (LA) | 194±14.7$^a$ | 1.62±0.12$^a$ | 1.66±0.05$^a$ | 638±48.30$^a$ | 97.5±0.71$^a$ | 1.41±0.03$^a$ |
| Rwasave site (MA) | 152±2.63$^b$ | 1.27±0.02$^b$ | 1.50±0.01$^b$ | 501±8.65$^b$ | 93.0±1.41$^b$ | 1.44±0.08$^a$ |

Values are the means and standard deviation between replicates. In the column, values with different superscripts are different ($p < 0.05$).
TWG - total weight gain, DWG - daily weight gain, SGR - specific growth rate, RGR - relative growth rate, SR - survival rate,
$K_m$ - coefficient of condition; (HA: High Altitude, LA: Low Altitude, MA: Middle Altitude)

**Table 2:** Feed utilisation of Common Carp in the three agro-climatic zones of Rwanda

| Sites | FI (kg) | FCR | FCE |
|---|---|---|---|
| Rukomo site (HA) | 120±10.3[b] | 2.24±0.24[ab] | 0.45±0.05[ab] |
| Gatunda site (LA) | 187±7.42[a] | 2.47±0.30[a] | 0.40±0.05[b] |
| Rwasave site (MA) | 111±4.24[b] | 1.98±0.27[b] | 0.50±0.07[a] |

Values are the means and standard deviation between replicates. In the column, values with different superscripts differed ($p < 0.05$).
FI - feed intake, FCR - feed conversion ratio,
FCE - feed conversion efficiency;
(HA: High Altitude, LA: Low Altitude, MA: Middle Altitude)

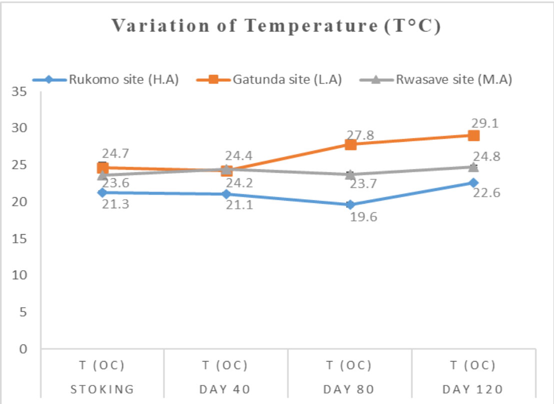


**Figure 3:** Variation of temperature in the three sampled agro-climatic zones during the study period
(HA: High Altitude, LA: Low Altitude, MA: Middle Altitude)

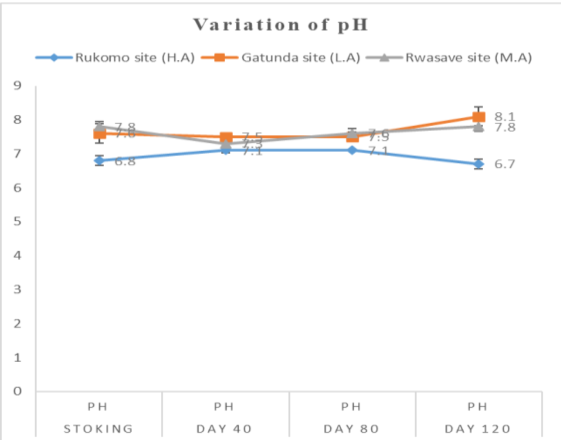


**Figure 4:** Variation of pH in the three sampled agro-climatic zones during the study period
(HA: High Altitude, LA: Low Altitude, MA: Middle Altitude)

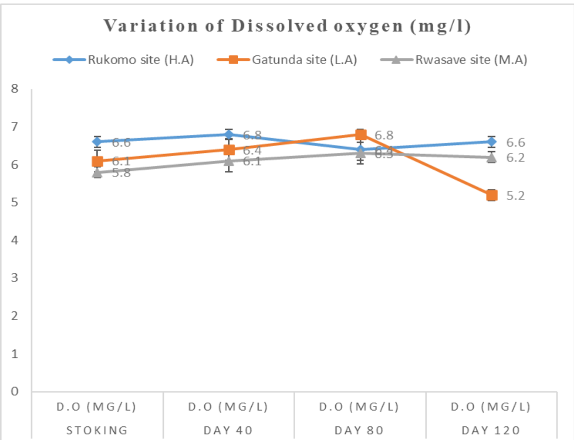


**Figure 5:** Variation of dissolved oxygen (mg $l^{-1}$) in the three agro-climatic zones during the study period
(HA: High Altitude, LA: Low Altitude, MA: Middle Altitude)

growth performance, with each species having an optimal temperature range for rapid growth. Deviations from this range, either too high or too low, can negatively affect growth, feed conversion, and overall health. Generally, there is an optimal temperature range for each species where growth is maximised. Outside this range, growth can be stunted, and at extreme temperatures, it can even be detrimental to their health (Boyd, 2018a). Even though the algal biomass was not determined in this study, the growth performance of Common Carp at the Gatunda site may apparently result from efficiency in ponds fertilization that triggered more natural food or phytoplankton that could have been consumed by carp fish than at the Rwasave and Rukomo sites. Indeed, pond fertilization can significantly enhance fish growth by increasing the availability of natural food sources like plankton and other aquatic organisms. Fertilization provides essential nutrients that promote phytoplankton and zooplankton blooms, which form the base of the pond's food web. This, in turn, leads to faster growth rates and higher yields for fish populations (Boyd, 2018b).

Globally, the results of this study indicated that growth performance of Common Carp was satisfactory across the three experimental agro-ecological zones of Rwanda when compared with the documented growth potential of Common Carp. Indeed, under suitable water temperature conditions, the different forms and strains of this species can reach an individual weight of approximately 0.2-0.3, 1-1.2 and 2.5-3.5 kg within about 2-3, 5-7 and 10-14 months, respectively, according to the FAO (2018). A slight decrease in growth performance observed in this study compared to growth potential of Common Carp might be as a result in low feed intake, hence Common Carp being bottom feeders, they may not efficiently consume floating pellets distributed at the water surface, resulting in uneaten feed.

In the present study, the daily weight gain (DWG) ranged from 1.16 ± 0.03 g day$^{-1}$, 1.27 ± 0.02 g day$^{-1}$, and 1.62 ± 0.02 g day$^{-1}$, while the specific growth rate (SGR) ranged from 1.43±0.02 % day$^{-1}$, 1.50 ± 0.01% day$^{-1}$, and 1.66 ± 0.05% day$^{-1}$ at the Rukomo, Rwasave, and Gatunda sites, respectively. These results indicate better growth performance compared with the findings of Mugo and Chege (2018), who reported that juvenile carp with an initial body weight of 5.3 ± 2.2 g reached 328 ± 6.8 g after 14 months. In their study, the fish recorded a DWG of 0.8 g day$^{-1}$, and SGR of 0.9% day$^{-1}$, and a survival rate of 95% in the high-altitude Mount Kenya region (1° 0′ 0″ S, 36° 46′ 0″ E; elevation, 3500 m). Similarly, Ondhoro *et al.* (2023) evaluated the growth and economic performance of Nile tilapia (*Oreochromis niloticus*), Mirror carp (*Cyprinus carpio*), and the exotic rainbow trout (*Oncorhynchus mykiss*) reared in earthen ponds in mid-altitude areas of Uganda, where temperatures ranged between 15 and 23 °C using locally available feeds. Their study demonstrated that mirror carp is

**Table 3:** Standard values of water quality in aquaculture

| Parameters | Desirables values | Acceptable values |
|---|---|---|
| Temperature | 29-30 ºC (optimal growth) | 20-32 ºC |
| (tropical species) | < 26-28 ºC (low growth rates) | < 10-15 ºC (lethal limit) |
| pH | 6.5-9.5 | 5.5-10.0 |
| Salinity | < 0.5ppm | - |
| TAN | 0-0.2 mg $l^{-1}$ | Less than 4 mg $l^{-1}$ |
| $NH_3$-N (un-ionised) | 0 mg $l^{-1}$ | Less than 0.4 mg $l^{-1}$ |
| $NO_2^-$ | 0-1 mg $l^{-1}$ | Less than 4 mg $l^{-1}$ |
| $NO_3^-$ | < 100 mg $l^{-1}$ | - |
| Alkalinity, total | 50-150 mg $l^{-1}$ as $CaCO_3$ | Above 20 mg $l^{-1}$ and less than 400 mg $l^{-1}$ |
| Hardness, total | 50-150 mg $l^{-1}$ as $CaCO_3$ | Above 10 mg$l^{-1}$ as $CaCO_3$ |
| $PO_4^{3-}$ | 0.005-0.05 mg $l^{-1}$ | - |
| TSS | < 300 mg $l^{-1}$ | - |
| DO | > 4.0 mg $l^{-1}$ | 1-10 mg $l^{-1}$ |
| Turbidity | < 10NTU in streams and rivers while < 30 NTU in lakes and ponds | - |
| Conductivity | 100-2000 µs $cm^{-1}$ | 30-5000 µs $cm^{-1}$ |

the most suitable species for aquaculture in mid-altitude environments in Uganda and that its production can be commercially viable when management practices are optimised. In contrast, Nile tilapia was found to be less suitable for culture under natural mid-altitude conditions.

It is worthy of note that, the daily weight gain of Common Carp can vary significantly, with average DWG between 3 and 5 g $day^{-1}$. Factors like diet, water temperature, stocking density, salinity, and rearing system influence growth, with some studies showing higher or lower average daily weight gain depending on these conditions (Ali *et al.,* 2022a; Jia *et al*., 2022). Majid *et al.* (2018) recorded a DWG ranging from 4.36 to 5.22 g $day^{-1}$ and SGR ranging from 1.99 to 3.10% $day^{-1}$ with carp juveniles of 102 g for a 3-month experiment cultivated in plastic tanks installed in semi-closed system.

Comparing the three agro-ecological zones, higher ($p < 0.05$) growth performance in terms of total weight gain (TWG), daily weight gain (DWG), specific growth rate (SGR), and relative growth rate (RGR) was observed at the Gatunda site, a low-altitude agro-climatic zone, compared with the Rwasave and Rukomo sites, which represent middle- and high-altitude zones, respectively. The superior performance observed at Gatunda may be attributed to more favorable water temperatures within the optimal range for Common Carp growth, as well as higher natural productivity, particularly phytoplankton availability, in the experimental ponds compared with the other two sites.

**Feed Utilisation**

Better feed utilisation was observed at the Rwasave site, where the feed conversion ratio (FCR) and feed conversion efficiency (FCE) differed ($p < 0.05$) compared with the Rukomo and Gatunda sites. This difference was associated with higher feed intake (FI), particularly at the Gatunda site. Typical FCR values in fish generally range from about 1.00 to 2.40 (Fry *et al.,* 2018) or from 1.20 to approximately 2.20, corresponding to FCE values of 0.83-0.45, depending on several factors such as feed type, fish species, animal size, feeding practices, and water quality conditions in aquaculture systems (Boyd, 2021). In some cases, FCR values of 1.00 or lower have been reported, especially in Salmonid culture. The FCR and FCE values recorded in this study fell within the ranges reported by Fry *et al.* (2018). However, the relatively poor feed utilisation parameters observed in this study may have led to the loss of a considerable portion of the distributed feed. This could be explained by the feeding behavior of Common Carp, which is a bottom-feeding species, whereas the feed used consisted of floating pellets. This inefficiency was likely not related to the protein (35%) or lipid content of the diet. The recommended protein level for the grow-out phase of Common Carp ranges from 30 to 35% (Watanabe, 1982; Jallit *et al*., 2023). The optimal dietary protein level for growth performance of Common Carp during the grow-out phase is around 30%, depending on culture conditions (Jallit *et al.*, 2023). Similarly, Shahabuddin *et al*. (2007) reported that 40% protein, 1-2% lipid, and 30% carbohydrate are required for optimal growth and development of Common Carp. In fact, because Common Carp are bottom feeders **(**Bajer *et al.*, 2009; Elias *et al.*, 2015), they may not efficiently consume floating pellets distributed at the water surface, resulting in uneaten feed. Instead, they tend to forage at the bottom of the pond, feeding on a variety of natural food items such as plants, invertebrates, and detritus.

**Water Quality**

Based on the standard values of water quality in aquaculture (Nathan and Hugh, 1977; Boyd, 1990; Wurts and Durborow, 1992; Boyd and Tucker, 1998; Zweig *et al*., 1999; Lindholm-Lehto *et al*., 2020; Yusoff *et al.,* 2024), the results obtained for all physico-chemical parameters showed that the values were found on their allowable range in the three sampled agro-ecological zones. Almost, all recorded temperatures in the three agro-climatic zones were within the range of thermal preference of Common Carp being 23-25 ºC (Boyd, 1990). However, the values of temperature recorded at Gatunda and Rwasave sites were more suitable than those recorded at Rukomo, hence the better growth performance observed in those two sites.

Dissolved oxygen (DO) levels were in desirable range in all sampled sites and globally varied from 5.2 to 6.8 mg $l^{-1}$. It can be assumed that the DO did not affect growth as the recorded measures were found at standard values of water quality in aquaculture. Indeed, Common Carp are generally tolerant of low oxygen conditions but exhibit varying oxygen consumption rates depending on factors like size, activity, and water temperature. This fish species can survive low oxygen concentration (0.3-0.5 mg $l^{-1}$) as well as super saturation and its ability to breathe air through gulping also helps them tolerate lower oxygen levels (FAO, 2009; Ali *et al*., 2022b).

The pH recorded during this study (6.8-7.8) was found in desirable range (6.5-9.5) of water quality in aquaculture. It could be stated that the pH did not affect the growth of carps in all sampled sites. Aquaculture species will usually die quickly, if the pH is less than 4 or greater than 11. Most species can fairly well tolerate a pH between 6 and 9, but they are usually stressed by pH outside this range resulting in less growth and greater susceptibility to disease. The optimum pH for most species is between 6.5 and 8.5 (Boyd, 2017; Khanjani *et al*., 2024).

## CONCLUSION

It could be concluded from this study that the Common Carp could be cultured in all agro-ecological zones and high-altitude areas of Rwandan territory. Nevertheless, the lower elevation zone; the Gatunda site where temperature is varying 24-29°C provides better growth performance to the Common Carp.

A slight decrease in growth performance observed in this study compared to the Common Carp growth potential was probably due to low feed intake, however globally the growth was relatively satisfactory. For further studies, it is recommended to use sinking pellets to increase the feed consumption, to improve the feed utilisation and to boost the growth performance of the species.

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