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A BSTRACT

The Nile tilapia, Oreochromis niloticus , is a widely cultivated fish throughout the world. The fish is particularly important for aquaculture in Nigeria due to its popularity. The objectives of this study are to investigate the effects of Lates niloticus DNA on growth performance, proximate composition, and DNA

fingerprint of O. niloticus . Various concentrations of DNA (0, 10, 20, 30, and 40 µg/µl) extracted from the Lates niloticus were injected into the somatic tissue of the Oreochromis niloticus fingerlings. The injected fish were raised for 120 days in a polyethylene mobile fish pond (2.5 x 1.5 x 1.2 deep). The r esults show that f ingerlings injected with 40 µg/µl have significantly (P<0.05) better final weight, weight gain, average daily weight gain, specific growth rate, crude protein , and metabolizable energy. RAPD g el electrophoresis revealed distinct banding patterns among the treated fish. The control fish had 5 bands, while fish injected with 10, 20, 30, and 40 µg/µL had 7, 6, 8, and 9 bands, respectively . Out of five loci, 80% were polymorphic. This study revealed that fragmented DNA materials from Lates niloticus have the potential to improve growth in Oreochromis niloticus . Fragment of L. niloticus DNA moderately integrated into the O. niloticus genome. The DNA of L. niloticus has significantly (p<0. 05) altered the proximate composition of Nile tilapia, especially by enhancing protein content and metabolizable energy. These changes could offer nutritional, economic, and production benefits in Tilapia aquaculture, though further investigation into safety, long-term performance, and consumer acceptance is essential.

Keywords: Aquaculture, DNA, Enhancement, Fish, Nile Perch, Somatic cell

I NTRODUCTION

Nile tilapia, Oreochromis niloticus , is one of the world's most widely cultured fish species, particularly in Africa, due to its high adaptability, rapid growth, and ability to thrive in diverse aquatic environments. According to (FAO, 2025), global Tilapia production reached about 6.2 million tonnes in 2023, making it the second most farmed freshwater fish after carp, while Roderic k (2025) reported that the Rabobank Global Seafood Specialist, Nikolik, estimated global Tilapia production will surpass 7 million metric tonnes in 2024. China remains the largest global producer, followed by Indonesia, while Egypt leads Africa, contributing nearly 1.5 million tonnes (60% of the continent's total production), followed by Nigeria with about 300,000 tonnes and other sub-Saharan countries like Ghana, Uganda, and Kenya (FAO 2025). Africa's estimated Tilapia production, therefore, is about 2.0–2.5 million tonnes (FAO, 2025). According to Steffens (2024), the Nile Tilapia plays an important global role in supporting food security, provides affordable, high-quality protein, helping combat malnutrition in developing countries, and provides income for smallholder farmers and fishers, supporting rural economies (Wasso et al ., 2024). Because of its affordability, the Nile Tilapia is sometimes considered a food for the poor, or the fish for the masses (El-Sayed, 2020).

Nile tilapia, Oreochromis niloticus , remains a key species in global aquaculture, but its growth performance has declined in many farmed populations due to genetic stagnation and inbreeding (Yousif et al ., 2026) . As demand for faster-growing, more efficient fish increases, there is a growing need for advanced techniques like DNA transfer to enhance growth and other economic traits. However, the potential of DNA transfer in improving the growth performance of Nile tilapia is still underexplored, particularly about how it may influence other traits such as growth and nutritional composition. This creates a vital research gap that warrants investigation. The genus Lates belongs to the family Latidae and is of the order Perciform, comprising eleven (11) species that occur in fresh and brackish water (Otero, 2004) . The Nile Perch, Lates

niloticus , belongs to the family Latidae of order Perciformes (Otero , 2004) , and is a freshwater species indigenous to African rivers and lakes, including the Nile, Chad, Senegal, Niger, and Congo River basins (Paugy, 2003; Liu, 2008) . The fish is found almost everywhere in West Africa, except in Gambia (Paugy, 2003). The fish is one of the freshwater fish Kaufman (1992) could serves as valuable genetic materials Haruna et al . (2025) for enhancing growth and other useful traits in fish, taking advantage of its size (growth vigour).

Many approaches can be used to improve the growth of the fish. One of the methods can be done through transgenesis (gene/DNA transfer). The most common method used to date is the microinjection of DNA/genes into the pronuclei of zygotes of fish (Shakweer et al . , 2023). DNA/gene can be manually injected into the skeletal muscles of fish (Wolff et al ., 1990). According to Sudha et al . (2001), a foreign gene can be transferred into fish in vivo by introducing DNA into embryos or directly into the somatic tissues of young or adult fish. Assem and El-Zaeem (2005) opined that the direct insertion of DNA into fish muscle is a simple approach that provides faster results and can eliminate the need for screening transgenic individuals and selecting germline carriers. According to Lin-Han et al . (2013), Electrotransfer of plasmid DNA into skeletal muscle is a common non-viral delivery system for the study of gene function and for gene therapy. Gene transfer and expression through intramuscular injection of foreign DNA into the skeletal muscles of fish has been achieved by Hansen et al . (1991), Rahman and Maclean (1992), Anderson et al . (1996), Tan and Chan (1997), Xu et al . (1999) , G o mez-Chiarri et al. El-Zaeem (2004), El-Zaeem and Assem (2004), and Hemeida et al . Moreover, Sudha et al . (2001) stated that the expression of muscular injection of DNA was evident in several nonmuscle tissues, such as skin epithelia, pigment cells, blood vessel cells, and neuron-like cells. The major limitation of intramolecular DNA/gene transfer is that expression may be transient, may not be stably inherited, because the injected DNA generally remains episomal and may not integrate efficiently (Lee et al ., 2013).

Several genes have now been introduced into various fish species to enhance growth, resistance to disease, tolerance to freezing, etc (Shears et al ., 1991; Chatakondi et al ., 1995; El-Zaeem, 2001, 2004; Dunham et al ., 2002; El-Zaeem and Assem, 2004 ; Guo et al ., 2021) . According to Dunham (2011), DNA transfer techniques have shown promising results in improving the growth performance of various fish species, including Nile Tilapia. In a study by El-Zaeem and Assem (2004), it was found that injecting shark DNA into the skeletal muscles of Oreochromis niloticus resulted in accelerated growth and improved body composition . Another study by El-Zaeem et al . (2011) observed higher body weight, feed utilization, and specific growth rate in Oreochromis niloticus injected with Seabream and Artemia salina DNA to enhance salt tolerance. According to El-Zaeem et al . (2012a), growth performance and body composition in red Tilapia injected with shark DNA were superior compared to non-injected Coptodon (Tilapia) zilli . El-Zaeem (2012b) reported improvements in growth performance and body composition of grey mullet fingerlings injected with shark DNA. Additionally, Martinez et al. (2000) reported a 290 % food conversion efficiency in transgenic tilapia compared to the control group. Genetically modified O. niloticus showed more than 80 % weight increase compared to non-modified strains (El-Zaeem, 2011). Rahman (2001) reported a mean mass of 653 g in O. niloticus containing an exogenous fish growth hormone gene after 7 months of culture,

representing a 2.5-fold increase in growth compared with non-transgenic siblings. Rahman et al . (2013) reported significant improvements in growth rates by 30 %, feed conversion efficiency, and overall biomass production in O . niloticus produced through gene transfer.

Genetically modified or transgenic Nile tilapia (Oreochromis niloticus) has been developed to enhance growth rates, disease resistance, and feed efficiency. Studies indicate that genetic modifications can influence the proximate composition of the fish, including moisture, protein, lipid, and ash conten t (Sharma and Sharma, 2021; Ahmed et al ., 2022) . Studies comparing transgenic and non-transgenic tilapia suggest that transgenic variants may exhibit higher protein content and altered lipid profiles, potentially due to enhanced metabolic activity (Guo et al ., 2021) . Several authors reported the proximate composition of Nile Tilapia: Job et al . (2015), Olopade et al . (2016), and Otene et al . The proximate composition of genetically modified Tilapia has been documented by El-Hawarry (2012), Kumara et al. (2020), Suwannatrai et al . (2023), and El-Zaeem et al . DNA fingerprinting effectively differentiates between closely related species or individuals by examining variations in genomic sequences (Du et al ., 2025). Molecular markers used in DNA fingerprinting include Restriction Fragment Length polymorphisms (RFLP), Random Amplification Of Polymorphic DNAs (RAPD), microsatellite, and single-nucleotide polymorphism (Boban et al ., 2022). Random Amplified Polymorphic DNA (RAPD) has been successfully used to differentiate species and subspecies of tilapia, such as Oreochromis niloticus , using polymorphic banding patterns generated by random primers (Bardakci and Skibinski, 1994). works by amplifying random segments of genomic DNA using short primers, producing unique banding patterns that reflect genetic variation (Dinesh et al ., 1993; Bardakci & Skibinski, 1994; Ali et al ., 2004). The RAPD serves as both forward and reverse primers, and is usually able to amplify fragments from 1–10 genomic sites simultaneously. They are quick and easy to assay, require a low quantity of DNA with no sequence data for primer construction (Welsh and McCelland, 1990).

Microinjection of Genomic DNA (gDNA) into another fish could affect the nutritional profile of the recipient (Gultom, 2023) . Proximate analysis of fish helps determine the nutritional profile of the fish and is one of the major indicators of fish quality for human consumption (Jannatun et al ., 2023). Determining the proximate composition of genetically modified fish ensures that the fish meat meets food high standards (Otene et al ., 2024) and ensures that genetic modification does not negatively impact the nutritional profile, making it a healthy protein source.

The constraints for the development and growth of Tilapia farming in Nigeria are slow growth due to poor seed quality TADAN, 2023) , early maturity, and high prolificacy. The high prolificacy leads to overpopulating the pond, resulting in stunted fish and a poor market. The use of synthetic hormones to control reproduction (sex reversal) to obtain fast-growing all-male Tilapia has been successful. However, the technology is cumbersome, coupled with global concern about the effect of this steroid (hormone) in fish flesh on humans and the environment. The knowledge of the fate of the residuals of the steroids in fish is still low (Mlalila et al . , 2015) . According to Hoga et al . (2018), as cited by Karaket et al. (2023), t he use of hormones, especially 17α-Methyltestosterone in Nile tilapia farming, has been of concern to

consumers as it involves potential risks to human health and environmental contamination by its residue. Additionally, the effects of the hormone and its residue on the vital organs of man are also uncertain. Natural hormonal sex reversal to produce all males Tilapia as an improvement in the growth of Tilapia has been attempted by several authors, Andri et al . (2010), Chukwu et al. (2012), Diyaware et al. Mohammed et al. (2024) , but with limited success (less than 100 % male). The re is a paucity of information on the effects of Lates niloticus DNA on the growth performance, proximate composition , and DNA fingerprint of Oreochromis niloticus in Nigeria. The objectives of th e study, therefo re , are to investigate the growth performance, proximate composition, and DNA fingerprint of O. niloticus containing Lates niloticus DNA.

Hypothesis:

H 1 = Lates niloticus DNA can significantly (p < 0.05) increase growth in O . niloticus via stable integration .

H o = Lates niloticu s DNA can not significantly (p < 0.05) increase growth in O . niloticus via integration .

M ATERIALS AND METHODS

Study Area

The study was conducted at the Teaching and Research Fish Farm of the Department of Fisheries, Faculty of Agriculture, University of Maiduguri, Nigeria. The study area is situated between latitude 11° 48 ' 41'' N and longitude 13° 12 ' 33'' E, with hot and cool periods as well as rainy (wet) and dry seasons. The wet season has a short duration of erratic rainfall of 3 - 4 months per year, with an approximate 519.34 mm, with annual totals ranging from 292.7 mm to 838.2 mm , with its peak in August , with the highest mean monthly rainfall of approximately 196.66 mm (Abatcha et al ., 2024) . During the dry season, ambient temperatures are lower in December and January, ranging from 15 - 20 °C (night), and higher in March to June at 33 - 47 °C (day). The relative humidity ranges between 33.5 - 34.5% (Kyari et al . , 2026)

Source of Donor Fish

The Nile Perch, Lates niloticus (300 - 456.0 g) were obtained from Karabonde landing site (Figure 1), Kainji Lake, Niger State, Nigeria. Karabonder landing site is situated between latitudes 9.899403° and longitudes 4.564203° .

Fig ure 1: Map of Niger State showing Karabonde landing site, Kainji Dam, Nigeria.

DNA Extraction and Quantification

Fifty (50) mg fin tissue samples of the Nile Perch, Lates niloticus , were collected, preserved in DNA-grade ethanol, and transported to the Northeast Biotechnology Centre, University of Maiduguri, Nigeria. Genomic DNA was extracted from the tissue of Lates niloticus following the protocol described by Baradakci and Skibinski (1994). The fin tissues were crushed into smaller pieces using a laboratory pestle and mortar and

homogenized using a tissue homogenizer. The crushed tissues were then transferred into a microcentrifuge tube containing 50 mM Tris Bis buffer, 100 mM EDTA (pH 8.0), 100 mM NaCl, 0.1 % SDS , and 0.5 mg/ml proteinase K, and incubated overnight for the samples to digest. After incubation, DNA was extracted twice for 15 - 20 minutes with a 1:1 ratio of phenol and chloroform and again twice for 15 min utes with 24:1 volume of chloroform and isoamyl alcohol. The aqueous phase was then precipitated with 2.5 volumes of 100% DNA grade ethanol in the presence of one-tenth volume of 3.0 M sodium acetate (pH 6.0). The DNA pellets were washed with 70 % DNA-grade ethanol and dissolved in 0.1 ml saline sodium citrate (SSC) buffer. The DNA concentration was measured at 260nm wavelength while purity was estimated at a ratio of A 260 /A 280 using an Ultraviolet (UV) Spectrophotometer (Model: Nanodrop 2000/2000c, Thermo-Scientific, USA) .

Experimental D esign

A total of 675 juveniles of Oreochromis niloticus (mean weight of 104.47 g and 5.47 cm length) were divided into five groups, with 135 juveniles per group (treatment , i.e., 45 fish per unit). Different concentrations of SSC buffer-based DNA: 0 as control, 10, 20, 30, and 40 µg/µ l with a final volume of 0.1ml were injected into the dorsal somatic tissue of 45 fingerlings using a thermodynamic micro-syringe and needle in three replicates . The fingerlings were then reared in a 3 x 2 x 1.2 m deep polyethylene fish pond at 7.5 fish/m 2 in three replicates arranged in a complete randomized design manner . The fingerlings were fed with a 35 % crude protein commercial diet at 5% body weight for 3 months , t twice daily at 9:00 am and 3:00 pm.

Growth Performance of O. niloticus Containing Exogenous DNA

At the end of the three-month rearing period, the final weight (g), final length (cm), fish mortality, and quantity of feed applied were recorded. We estimated the following growth indices for each treatment:

Weight gain (g) = W 2 – W 1, where W 2 and W 1 are the final and initial weights of the fish, respectively.

Percentage weight gain = W2 - W1 x 100, w1

Mean Daily Weight Gain (MDWG) in grams = W2-W1t, t = the culture period (days).

Specific Growth Rate (SGR % per day) = InlogW2-InlogW1t x 100, where In. logW 2 =

natural log of final weight, In.log W 1 = natural log of initial weight, and t = culture

period (Busacker et al ., 2012).

Feed conversion Ratio (FCR) = Dry weight of feed weight gain of fish

vi) Survival (%) = No. of fish survived. of fish stocked x 100.

Monitoring of Water Quality

Time series water quality was monitored during the study. The temperature (o C), pH, electrical

conductivity (µS /c m), and total dissolved solids (ppm) were measured using a Multifunction 4 - in -1 T emp./ EC / TDS /p H Meter (M odel : 9908, China) , and dissolved oxygen was recorded using a portable digital DO meter (Model: BLE-9100).

Proximate Composition of O. niloticus Improves Through DNA Transfer.

One hundred and f ifty (1 50) g of fish muscle from each treatment were collected and placed in an icepack containing ice flakes and shipped to the Animal Care quality control laboratory, Kano State, Nigeria, for proximate composition. Before the proximate analysis, wet chemistry calibration against the AOAC standard was done. To calibrate against standard methods (AOAC 2023 wet chemistry), 50g representative of fish samples containing L. niloticus DNA were collected and subjected to proximate composition analysis using standard wet chemistry methods as described in the AOAC International (2023) . Moisture content was determined by oven drying at 105 °C until constant weight. Crude protein was analysed using the Kjeldahl method, Crude lipid was measured by Soxhlet extraction with petroleum ether, Ash content was determined by incineration in a muffle furnace at 550 °C, and crude fibre was analysed using the enzymatic gravimetric method. The same fish samples were scanned using the Near-Infrared Reflectance (NIR) multi-checker across the spectral range of 780–2500 nm. Spectral data were processed using Partial Least Squares (PLS) regression to establish calibration equations by correlating NIR absorbance patterns with the AOAC-verified wet chemistry values. Calibration models were validated with independent fish samples, and prediction accuracy was assessed using the Root Mean Squared Error of Prediction (RMSEP). The proximate composition was conducted in triplicate using a digital Near Infrared (NIR) Multi-Checker (Model: 21MC11309A06, China) according to AOAC Internationa l (20 23) . While metabolizable energy was estimated using Atwater conversion factors , the NRC (2011) formula:

w here CP = Crude Protein (%), EE = Ether Extract / Crude Fat (%), and NFE = Nitrogen Free Extract (%)

RAPD Protocol/Fingerprint Analysis

At the end of the experiment, 50 mg tissue from each treatment (including the control) in three replicates was collected after sedation according to the method described by Diyaware et al . Three tissue samples were also collected from the donor fish (L. niloticus). The samples were stored at −20°C until DNA extraction. Genomic DNA was extracted from the tissues following the protocol described by Baradakci & Skibinski (1994). Each tissue was crushed individually into smaller pieces using a laboratory pestle and mortar and homogenized using a tissue homogenizer. The crushed tissues were then transferred into separate microcentrifuge tubes containing 50 mM Tris Bis buffer, 100 mM EDTA (pH 8.0), 100 mM NaCl, 0.1 % SDS, and 0.5 mg/ml proteinase K, and incubated overnight for the samples to digest. After incubation, DNA was extracted twice for 15 - 20 minutes with a 1:1 ratio of phenol and chloroform and again twice for 15 min utes with 24:1 volume of chloroform and isoamyl alcohol. The aqueous phase was then precipitated with 2.5 volumes of 100 % DNA grade ethanol in the presence of one-tenth volume of 3.0 M sodium acetate (pH 6.0). DNA pellets were washed with 70 % DNA-grade ethanol and dissolved in 0.1 ml saline sodium citrate (SSC) buffer. The DNA concentration was measured at 260nm wavelength, while purity was

estimated at a ratio of A 260 /A 280 using an Ultraviolet (UV) Spectrophotometer (Model: Nanodrop 2000/2000c, Thermo-Scientific, USA).

Polymerase Chain Reaction

Polymerase Chain Reaction (PCR) reactions were performed in 25 µL volumes containing 10 × PCR buffer, 2.0 mM $MgCl_2$, 0.2 mM dNTPs, 1.0 µM primer, 1 U Taq DNA polymerase, and 20–50 ng template DNA. Three RAPD primers modified from Ogbuebunu & Awodiran (2017) were used for the PCR (Table 1). All primers were amplified at an initial denaturation of 94 °C for 3 minutes, 40 cycles, denaturation temperature of 94 °C for 30 seconds, annealing temperature of 36 °C for 1 minute, extension at 72 °C for 1 minute, final extension at 72 °C for 10 minutes, and holding temperature of 4 °C.

Table 1: Random Amplified Polymorphic DNA (RAPD) Primer Sequences

Primers	Primer Sequence
OPH-05	AGTCGTCCCC
OPT-06	CAAGGGCAGA
OPT-20	GACCAATGCC

Gel E lectrophoresis

Polymerase chain reaction (PCR) products were resolved on 1.5 % agarose gels at a voltage of 70V for 40-50 minutes, stained with ethidium bromide. The gels were visualized under gel documentation Ultraviolet (UV) light plate and photographe d. Banding patterns were compared between the fish that recieved the DNA and the control fish. The presence of unique bands in injected fish was interpreted as evidence of foreign DNA integration.

Scoring , A nalysis of RAPDs , and Estimation of the Molecular Weight

The genotypes were determined by recording the presence (1) or absence (0) of bands in the RAPD profiles . The dendrogram was then constructed using Euclidean c luster analysis. The molecular weights of RAPD

fragments were estimated according to the method described by Sambrook & Russell (2001) by comparing their electrophoretic mobility with that of a standard DNA ladder. Migration distances (cm) of the marker bands were measured from the wells to the center of each band, and a standard curve was constructed by plotting the logarithm (log_{10}) of the known fragment sizes (bp) against their migration distances. The sizes of RAPD bands were then interpolated from this curve.

Data A nalysis

Data obtained on growth performance indices, proximate composition, and water quality were subjected to a O ne-way A nalysis of V ariance (ANOVA) . The differences between the means were determined using Tukey's Least Significant Difference (LSD) at 95% confidence level (p <0.05) with the aid of Statistix 8.0 . The RAPD fingerprints generated for all samples were scored using a Gel analyzer. The genetic diversity was determined using GenAlex (Peakall and Smouse, 2012) . Phylogenetic trees to check genetic distance were constructed using Nei’s (1972) Unweighted Pair Group Method with Arithmetic Mean (UPGMA) Euclidean Cluster analysis with the aid of PAST 4.03.

RESULTS AND DISCUSSION

Water Quality Parameters

Table 1 shows the time series water quality parameters observed during the study. D issolved O xygen (DO) ranged from 6 . 2 0 to 6. 4 8 mg/l in May, 641- 6.66 mg/l in June , 640- 6.80 mg/l in July, and 6.15-6.80 in August. While the temperature ranged between 30.80- 32.20, 28.70- 29.80, 28.30-29.80, and 28.60-29.33 °C in May, June, July, and August, respectively. No significant variance (p>0.05) was observed between the DO in May, June, and July, except in August, where significant differences (p>0.05) were observed between the DO values among the rearing tanks. The pH values in the culture media during May were between 7.48 and 8.34, in May, 8-8.62 in June, 8-8.90 in July, and 7-8.01 in August. The TDS were between 93.0 - 125.33 (ppm) in May, 150.33 – 162.33 (ppm) in June, 150 – 152 in July, while in August the TDS were between 107 - 127.67 (ppm). and EC ranged between 186-251.33 (µs/cm) in May 301- 308. (µs/cm) June, while in July and August the EC were between 255-305 and 212 - 257.33 µ S /cm, respectively.

The variations in the dissolved oxygen contents in the culture medium might have affected the growth performance among treatment groups and the survival, despite the fact that all the water quality parameters observed were within the recommended range for Tilapia culture (Boyd and Tucker, 1998).

Table 2 : Time Series w ater quality parameters observed during the study

Parameters
Deoxyribonucleic Acid (DNA) Concentration (µg/µl)

Abd El Hamied (2009) and Elwan (2009) observed improved growth performance, feed utilization, and other quantitative traits in O. niloticus injected with foreign DNA. Higher growth indices in fish injected with higher DNA may indicate transient expression or epigenetic effects, as suggested by Konstantinidis et al . Feed Conversion Ratio (FCR) was significantly ($p<0.05$) higher (1.46 ± 0.07) , in fish injected with 20 (µg/µL) DNA. There were no significant variations ($p<0.05$) were observed in the FCR of fish injected with 10 and 30 µg/µL) DNA comapred to those injected with 20 µg/µL . Significant variations ($p>0.05$) were observed in FCR of fish injected with 40 (µg/µL) DNA compared to those injected with 10-30 (µg/µL) L. niloticus DNA and control fish. The FCR of O. niloticus injected with L. niloticus DNA in this study was lower than 1.88 and 1.89 reported by El-Zaeem (201 2) for grey mullets (Mugil cephalus) injected with Shark DNA in to . The FCR was also lower than 1.83 reported by El Zaeem et al. (2023) in Coptodon zilli following injection with shark DNA and 1.5 reported by Krivins (2024) for O. niloticus fed a commercial diet. The variation may be due to differences in the fish species , rearing conditions and the sources of the DNA , and the degree of domestication selection the species must have undergone . The lower FCR observed in this study may also be due to the trade-off between growth acceleration and nutrient utilization. This trade-off between growth acceleration and nutrient utilization efficiency has been reported in several studies on transgenic and genetically improved fish. El-Zaeem et al . (2009) observed that shark DNA injected into red tilapia improved growth and feed utilization, but optimal efficiency was achieved under moderate dietary protein levels, suggesting that excessive stimulation may compromise metabolic balance. Rahman et al . (2001) confirmed that transgenic tilapia are also more efficient in utilizing protein and energy.

The survival of O. niloticus exposed to varying concentrations of L. niloticus DNA (0–40 µg/µL) ranged between 23.33% and 27.67%, with no significant differences ($p>0.05$) among treatments. This indicates that DNA concentration did not affect survival. This is consistent with earlier reports that tilapia tolerate foreign DNA exposure without major mortality effects (Rahman et al ., 1998; El-Zaeem, 2012; Konstantinidis et al ., 2020). The relatively low overall survival likely reflects environmental or handling stress, which has been shown to exert a stronger influence on tilapia survival than genetic manipulation (Omweno, 2023; Ahmed, 2023).

The Growth Pattern of O. niloticus, Containing Exogenous Fish DNA

The growth pattern of O. niloticus , containing exogenous fish DNA, is illustrated in Figure 2. A significant ($p<0.05$) progressive growth increase was observed with the increase in DNA concentration throughout the study. The L. niloticus DNA transfer had a dose-dependent relationship (Fig. 1). The progressive growth pattern may indicate that fish containing high concentrations of DNA might have efficiently utilized the diet given to them. Fu et al . (1998) reported that transgenics were more efficient in utilizing dietary protein compared to their non-transgenic siblings. Rahman et al . (2001) confirmed that transgenic tilapia are also more efficient in utilizing protein and energy.

Fig ure . 2: Growth pattern of O. niloticus containing exogenous fish DNA

Proximate Composition of O. niloticus Containing Exogenous Fish DNA

Table 3 shows the p roximate composition of O . niloticus containing exogenous fish DNA. Crude protein (CP) content increased significantly (p<0.05) with an increase in the DNA concentration. A higher CP of 39.05 % was observed in fish injected with 40 µg/µl of DNA, followed by 36.36 % CP in fish injected with 30 µg/µl of DNA. A lower CP of 27.90 % was observed in the control group , suggesti ng that the foreign DNA might have enhanced muscle protein synthesis in the Nile Tilapia.

The protein contents observed in this study were higher than 14.62 % CP observed in red belly tilapia (Coptodon zilli) injected with Shark DNA, as observed by El-Zaeem et al . (2023), and 11.32, 13.10, and 9.80 % in O . niloticus , O . aureus , and their hybrids, respectively, as documented by El-Hawarry (2012). Suwannatrai et al . (2023) reported 14.27 % crude protein of O. niloticus from Sakon Nakhon province, Thailand, while Kumara et al. (2020) noticed 7.85 % crude protein in O. niloticus from Sri Lanka. The variation in the crude protein level may be due to the differences in the fish species, the source of the DNA, and the age of the fish. However, Mukti et al . (2020) reported 85.70 and 87.00 % crude protein in triploid male and female O. niloticus , respectively. The greater variation observed in the crude protein levels of the sterile Tilapia compared to the tilapia containing foreign DNA could be due to the complete utilization of feed for growth only by the fish, rather than growth and reproduction as occurs in the fertile Tilapia containing foreign DNA. Martinez et al . (2000) reported an increased protein synthesis and growth rate concomitant with enhanced glycolysis and oxidation of amino acids in juvenile O. niloticus containing cDNA growth hormone . The increase in crude protein level observed in the fish injected with 40 µg/µl L. niloticus DNA may be due to the effective conversion of sparing nutrients from fish feed by the fish. A similar trend was also reported by Yuvarajan et al . (2019) in Genetically Improved Farmed Tilapia (GIFT), which recorded a remarkable increment in protein and lipid contents. Such an increase implies improved nutritional quality, which is important for Tilapia aquaculture profitability (Cebeci et al ., 2020) and improves the public health of consumers. Abd El Hamied (2009) and Elwan (2009) reported HIGHER body composition, in O. niloticus injected with foreign DNA

Table 4 : Proximate Composition of O . niloticus Containing Ex ogenous Fish DNA.

Nutrients
DNA Concentration (µg/µl)
CP
Ash
EE
CF

Moisture

ME(Kcal)

Means in the same column having similar superscripts are not significantly different (p>0.05).

Key: CP = Crude protein, EE = Ether extract, CF = Crude fiber, ME = Metabolizable energy.

Ash

Ash levels showed no significant variation (p>0.05) among the entire treatments. This suggests that DNA transfer had minimal effect on mineral content. The significance of ash contents among the treatments aligns with studies that ash is less sensitive to genetic or dietary manipulation (Abdel-Tawwab et al ., 2010). The ash contents observed in this study are lower than 1.36 % for O. niloticus and hybrid red tilapia by Olopade et al . (2016) in Nigeria and 2.27±0.34 reported by Kamruzzaman et al . 2018) for O. niloticus collected from Mymensingh Messua Baza of Bangladesh.

Ether Extract

Ether Extract (EE) was significantly (p<0.05) higher (13.12±0.3 and 12.47±0.02 %) in fish treated with 10 and 40 µg/µl DNA, respectively . The lowest EE (9.16±0.03 %) value was observed in fish containing 30 µg/µl DNA concentration. Generally, there were significant variations (p<0.05) among the mean values of the EE across all the treatments. The ether extract content, which reflects the lipid concentration in fish, showed noticeable (p<0.05) variations across the treatments. High lipid levels, especially in fish containing 10 and 40 µg/µl DNA, may indicate altered lipid metabolism probabbly due to foreign DNA expression. The observed (9 - 13 %) EE may indicate that the foreign DNA could have influenced lipid metabolism in the Nile tilapia. Genetic modification, particularly through DNA/gene transfer, is known to impact lipid regulation pathways. A similar trend was observed in transgenic mice containing silencing genes (SREBP-1c and PPARα), which significantly changes lipid synthesis and fatty acid oxidation (Horton et al ., 2002). Devlin et al . (2001) demonstrated that transgenic salmon exhibited increased lipid accumulation due to enhanced growth signals, suggesting that similar mechanisms might explain the ether extract changes observed in this study. Therefore, while moderate increases in EE could enhance nutritional value, careful optimization is required to balance consumer health concerns and product quality. Similarly, higher ether extract in the fish containing the foreign DNA may result in beneficial fatty acids such as Omega-3, which can enhance the fish's health value as suggested by Tocher (2003).

Crude fibre was observed to be significantly (p<0.05) h igher (1.64±0.03%) in fish injected with 10 µg/µl DNA compared to the entire treatment. The lowest (0.92±0.01%) crude fibre content was observed in the group injected with 40 µg/µl DNA. The crude fibre observed in this study is higher than 0.98 % reported by Yuvarajan et al . (2019) in Genetically Improved Farmed Tilapia (GIFT) and 0.54 and 0.59 % reported by Olapode et al . (2016) for O. niloticus and hybrid red tilapia, respectively. The variation in the fibre content may be due to strain variation (GIFT, normal tilapia, and the hybrids). Although fish naturally contain low

fiber, these changes may reflect alterations in gut microbiota or feed digestion due to genetic influence. Bolawa et al . (2011) reported very low crude fibre, while Otene et al. (2024) found fibre values consistently to be below 1 %, emphasizing that fish muscle is not a source of dietary fibre.

Moisture Content

Moisture content increases with an increase in DNA concentration, with the significantly (p<0.05) highest (63.94%) mean value in fish that received 40 µg/µl DNA. This trend suggests a positive correlation between DNA concentration and moisture retention in fish. The higher moisture contents observed in this are lower than 81.39 and 80.09 % observed by Olopade et al . (2016) for O. niloticus and hybrids of red Tilapia, respectively. El-Hawarry (2012) reported 79.09, 79.12, and 80.45 % moisture contents of fillets of O . niloticus , O . aureus , and their hybrids. The high moisture content observed in fish injected with a higher dosage of DNA may indicate that the muscle tissue of the fish retains more water, which could affect texture, shelf life, and susceptibility to spoilage (perishability). Wang and Zheng (2025) emphasize that enzymatic autolysis, lipid oxidation, and microbial growth are the main drivers of fish spoilage, all of which are facilitated by high moisture levels in the fish . Elevated water retention may be associated with changes in muscle plasticity and gene regulation, as recent studies highlight the role of DNA methylation and microRNAs in modulating muscle growth and water-binding properties in fish (Koganti et al ., 2020) . Significant variation (p<0.05) was observed between the mean moisture contents of the fish treated with 10 µg/µl DNA compared to the entire treatments. However, no significant variations were observed among the moisture contents of fish treated with 0, 20, and 30 µg/µl DNA.

M etabolizable Energy

Metabolizable energy wa s significantly higher (3474.10±91.36 Kcal) in fish treated with 40 µg/µl DNA, followed by (2970 ± 3.0 K cal) in fish treated with 30 µg/µl DNA . The increase in the Metabolizable energy (ME) with an increase in concentration of the DNA may indicate improved nutrient density and energy utilization, possibly reflecting metabolic shifts which might have been influenced by the presence o f foreign DNA sequences related to growth or feed efficiency. According to Thabet et al. (2025), foreign DNA can upregulate metabolic efficiency, thereby increasing metabolizable energy concentration. Konnert et al . (2022) opined that high ME indicates efficient nutrient conversion in the fish, which translates to better protein and fat availability for human consumption.

Fingerprint Random Amplified Polymorphic DNA Analysis

The DNA purity used in this study was 1.76 ng/µL at A260/A280 and 1.09 at A260/A230. Fig . 3 is the RAPD gel representative of O. niloticus injected with L.niloticus DNA. Gel electrophoresis revealed distinct banding patterns: the control fish had 5 bands, while fish injected with 10, 20, 30, and 40 µg/µL had 7, 6, 8, and 9 bands, respectively, suggesting probable differential integration or transient expression of L . niloticus DNA fragments among the treated fish. The donor fish DNA fragment wa s approximately 300 bp in size, based on its position relative to the 250 bp and 500 bp ladder bands.

Fig. 3: Gel representative of the DNA fingerprint of O . niloticus containing L . niloticus DNA

Out of five loci scored, four were polymorphic, corresponding to 80% polymorphism . The 80% polymorphism observed in this study may be an indicator of genetic variability likely induced by the injected L . niloticus DNA. The observed polymorphism in RAPD profile may reflect genetic differences associated with introduction of L. niloticus DNA (Williams et al ., 1990). The 80 % polymorphysim obser v ed in this study is higher than 50-70% for healthy fish populations as suggested by Ali et al. However, the high polymorphism observed in this study is less than 98.9% observed in Genetically Improved Farmed Tilapia (GIFT) reported by Oliveira et al . (2011) using RAPD. The variation could be due to differences in the genetic improvement method; GIFT tilapia were improved through selection, which has high heritability, while DNA injected into the muscle is taken up by muscle cells and may be expressed locally , hence the effect may be somatic and transient (Heppell and Davis, 2000). The presence of polymorphic loci may suggest introgression of L. niloticus DNA. While genetic variability can enhance resilience to environmental stress and disease (Weising et al., 2005), these findings align with earlier reports by Sambrook and Russell (2001) that RAPD analysis is effective in revealing high levels of polymorphism in fish .

The exhibition of different banding patterns may indicate genetic variation among the fish. The 250 bp band appears to correlate with increasing DNA concentration in O.niloticus , which may suggest a gene or DNA fragment silently or transiently expressed or integrated more at higher concentration ADDIN EN.CITE <EndNote><Cite><Author>Kusa</Author><Year>2026</Year><RecNum>851</RecNum><DisplayText>(Kusa et al., 2026)</DisplayText><record><rec-number>851</rec-number><foreign-keys><key app="EN" db-id="pda9x2rek52fr8e0s2q5tfeq05ae29dtztva" timestamp="1773666915">851</key></foreign-keys><ref-type name="Journal Article">17</ref-type><contributors><authors><author>Kusa, Thami</author><author>Diyaware, Mohammed Yakubu</author><author>Suleiman, Sa’adu Bala</author><author>Aliyu, Mohammed</author><author>Mohammed, Zanna Barde</author><author>Ajibike, Abdulhakeem Biola</author><author>Popoola, Omoniyi Michael</author><author>Haruna, Mohammed Yakubu</author></authors></contributors><titles><title>Growth response and some spawning indices of Nile Tilapia (Oreochromis niloticus, Linnaeus 1758) containing piscine DNA</title><secondary-title>The Journal of Basic and Applied Zoology</secondary-title></titles><periodical><full-title>The Journal of Basic and Applied Zoology</full-title></periodical><volume>87</volume><number>1</number><dates><year>2026</year></dates><isbn>2090-990X</isbn><urls></urls><electronic-resource-num>10.1186/s41936-026-00547-9</electronic-resource-num></record></Cite></EndNote> (Kusa et al. , 2026) . The 500 bp band, observed in fish injected with 30 and 40 µg/µL, might be a unique RAPD fragment only expressed or detectable at higher DNA concentrations, and is possibly a dose-sensitive gene or regulatory element activated at higher DNA loads.

The presence of distinct bands in the injected fish and their absence in controls may indicated transient

DNA expression on DNA damage or stress cause d by the foreign DNA. Intramuscular DNA delivery in fish is known to produce temporary expression of foreign genes. For instance, DNA vaccine studies in salmon and tilapia show that injected DNA can be transcribed in muscle fibers for a limited period before degradation (Heppell and Davis, 2000). Foreign DNA can activate DNA repair pathways in muscle cells and s keletal muscle exposed to exogenous DNA may undergo fragmentation due to nuclease activity and repair enzyme activation (Dey et al ., 2023). T he distinct bands may be a stress response to the injected foreign DNA. According to Petitjean et al . (2019) and Yuan et al . (2025) , s tress in fish alters gene expression and DNA stability . The unique fragments may therefore reflect stress induced molecular changes in tilapia muscle.

Assem and El-Zaeem (2005) reported integration of Shark DNA into the genome of Tilapia zilli (Coptodon zill ii) after direct injection. In a similar vein, El-Zaeem et al . (2011) reported the random integration of sea bream and Artemia DNA into O. niloticus genomes. They claimed that the integrations could be a functional or a silent integration, as suggested by Yaping et al . Fujimura and Kocher (2011) demonstrated efficient transgenesis in O. niloticus using the Tol2 transposon system, achieving approximately 30% germline transmission and strong Green Fluorescent Protein (GFP) expression. Similarly, Olabode et al . (2014) reported successful integration of growth hormone genes using Tol2-mediated microinjection, with PCR confirmation and enhanced growth in transgenic tilapia.

The L. niloticus DNA injected into O. niloticus may have induced genomic alterations or changes in RAPD amplification patterns, resulting in observed polymorphic RAPD profiles. Zhang et al . (1994) demonstrated that RAPD analysis detected genomic changes in tilapia following microinjection of foreign DNA, with altered banding patterns compared to non-injected controls.

RADP B anding and Fragment size of O. niloticus containing L. niloticus DNA

Table 5 shows the mean m olecular w eights of DNA b ands in O. niloticus treated with L. niloticus DNA. Electrophoresis of O. niloticus containing L. niloticus DNA revealed DNA fragments between 430 and 540 bp, while the donor fish had an average of 565 bp. Lower concentrations (0 µg/µL) were associated with the smaller fragments (430 bp), while moderate doses (10–20 µg/µL) yielded larger fragments (502–540 bp). At higher concentrations (30–40 µg/µL), fragment sizes decreased slightly (452–475 bp), suggesting possible saturation or degradation effects. These results align with the principle that DNA migration is inversely related to fragment size (Lee et al ., 2012). The clustering of fragments near the donor reference (565 bp) suggests that injected DNA was maintained long enough to be detected, consistent with transient expression of foreign DNA (Li et al ., 2019). While Variability across concentrations may reflect epigenetic regulation, as mechanisms like DNA methylation and histone modification can silence or exert influence on injected DNA activities (Bird, 2007; Zhang et al ., 2020). In tilapia, epigenetic responses to exogenous DNA have been shown to influence fragment stability and retention (Akinwale et al ., 2023). Thus, the observed patterns highlight the interplay between transient expression and epigenetic control in shaping the fate of donor DNA within host genomes.

Table 5: Mean Molecular Weights of DNA Bands in O. niloticus Injected with L. niloticus DNA

DNA Concentration (µg/µL)	Mean Fragment Size (bp)
0 (control)	
Donor fish	

Genetic Similarity I ndices

The dendrogram generated from gel electrophoresis banding profiles using UPGMA (F ig . 4) cluster revealed distinct groupings among fish that received L . niloticus DNA. The control fish (0 µg/µL of DNA) clustered separately from the donor fish, indicating genetic dissimilarity from their sibling that received DNA. In contrast, samples that received 10 to 20 µg/µL DNA showed progressive clustering toward L . niloticus , suggesting a dose-dependent assimilation of L . niloticus genetic material. Oreochromis niloticus injected with 30 and 40 µg/µL DNA formed a close cluster, indicating close similarity. The donor fish (L . niloticus) clustered separately . The O . niloticus injected 10 µg/µL exhibited moderate bootstrap, indicating that it is closer to O . niloticus than those injected with 30 and 40 µg/µL DNA .

Fig . 4 : Phylogenetic tree based on Nei's (1972) standard genetic distances using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) method generated from RAPD data. Key : DFish = Donor fish (Lates niloticus).

Overall, the dendrogram supports the hypothesis that the increasing DNA concentration enhances slight genetic similarity to the source organism, with 30 – 40 µg/µL representing a potential threshold for effective transient transformation.

Genetic Variability

This pattern of closer cluster formation of fish that recieved higher DNA concentration implies that higher DNA concentrations could have enhanced genomic integration or expression, which is consistent with previous findings in transgenic fish by Zhang et al . (2010) and Agha et al . The moderate bootstrap exhibited by fish injected with DNA closer to the donor fish, (L. niloticus) , suggests partial uptake or variability in transformation efficiency. These findings align with earlier reports by Sneath & Sokal (1973), Rohlf (2000), Fu et al . (2021), and Georgieva (2022) that hierarchical clustering can effectively resolve genetic relationships in electrophoretic data.

Conclusion

This study revealed that fragmented DNA materials from Lates niloticus may potentially improve growth in Oreochromis niloticus . Fragment of L. niloticus DNA transiently integrated into the O. niloticus genome.

#	Sentence	AI Score	Label
85	Proximate analysis of fish helps determine the nutritional profile of the fish and is one of the major indicators of fish quality for human consumption (Jannatun et al ., 2023).	77%	AI
86	Determining the proximate composition of genetically modified fish ensures that the fish meat meets food high standards (Otene et al ., 2024) and ensures that genetic modification does not negatively impact the nutritional profile, making it a healthy protein source.	75%	AI
87	The constraints for the development and growth of Tilapia farming in Nigeria are slow growth due to poor seed quality TADAN, 2023) , early maturity, and high prolificacy.	47%	Mixed
88	The high prolificacy leads to overpopulating the pond, resulting in stunted fish and a poor market.	65%	Mixed
89	The use of synthetic hormones to control reproduction (sex reversal) to obtain fast-growing all-male Tilapia has been successful.	68%	Mixed
90	However, the technology is cumbersome, coupled with global concern about the effect of this steroid (hormone) in fish flesh on humans and the environment.	67%	Mixed
91	The knowledge of the fate of the residuals of the steroids in fish is still low (Mlalila et al . , 2015) .	67%	Mixed
92	According to Hoga et al .	64%	Mixed
93	(2018), as cited by Karaket et al.	18%	Human
94	(2023), t he use of hormones, especially 17α-Methyltestosterone in Nile tilapia farming, has been of concern to consumers as it involves potential risks to human health and environmental contamination by its residue.	67%	Mixed
95	Additionally, the effects of the hormone and its residue on the vital organs of man are also uncertain.	72%	AI
96	Natural hormonal sex reversal to produce all males Tilapia as an improvement in the growth of Tilapia has been attempted by several authors, Andri et al .	64%	Mixed
97	(2010), Chukwu et al.	50%	Mixed
98	(2012), Diyaware et al.	50%	Mixed
99	Mohammed et al.	50%	Mixed
100	(2024) , but with limited success (less than 100 % male).	53%	Mixed
101	The re is a paucity of information on the effects of Lates niloticus DNA on the growth performance, proximate composition , and DNA fingerprint of Oreochromis niloticus in Nigeria.	60%	Mixed
102	The objectives of th e study, therefo re , are to investigate the growth performance, proximate composition, and DNA fingerprint of O. niloticus containing Lates niloticus DNA.	52%	Mixed
103	H 1 = Lates niloticus DNA can significantly (p < 0.05) increase growth in O . niloticus via stable integration .	45%	Mixed
104	H o = Lates niloticu s DNA can not significantly (p < 0.05) increase growth in O . niloticus via integration .	31%	Human
105	The study was conducted at the Teaching and Research Fish Farm of the Department of Fisheries, Faculty of Agriculture, University of Maiduguri, Nigeria.	76%	AI
106	The study area is situated between latitude 11° 48 ' 41'' N and longitude 13° 12 ' 33'' E, with hot and cool periods as well as rainy (wet) and dry seasons.	70%	Mixed
107	The wet season has a short duration of erratic rainfall of 3 - 4 months per year, with an approximate 519.34 mm, with annual totals ranging from 292.7 mm to 838.2 mm , with its peak in August , with the highest mean monthly rainfall of approximately 196.66 mm (Abatcha et al ., 2024) .	72%	AI
108	During the dry season, ambient temperatures are lower in December and January, ranging from 15 - 20 °C (night), and higher in March to June at 33 - 47 °C (day).	74%	AI
109	The relative humidity ranges between 33.5 - 34.5% (Kyari et al . , 2026)	76%	AI
110	The Nile Perch, Lates niloticus (300 - 456.0 g) were obtained from Karabonde landing site (Figure 1), Kainji Lake, Niger State, Nigeria.	55%	Mixed
111	Karabonder landing site is situated between latitudes 9.899403° and longitudes 4.564203° .	42%	Mixed
112	Fig ure 1: Map of Niger State showing Karabonde landing site, Kainji Dam, Nigeria.	26%	Human
113	Fifty (50) mg fin tissue samples of the Nile Perch, Lates niloticus , were collected, preserved in DNA-grade ethanol, and transported to the Northeast Biotechnology Centre, University of Maiduguri, Nigeria.	63%	Mixed
114	Genomic DNA was extracted from the tissue of Lates niloticus following the protocol described by Baradakci and Skibinski (1994).	66%	Mixed
115	The fin tissues were crushed into smaller pieces using a laboratory pestle and mortar and homogenized using a tissue homogenizer.	72%	AI
116	The crushed tissues were then transferred into a microcentrifuge tube containing 50 mM Tris Bis buffer, 100 mM EDTA (pH 8.0), 100 mM NaCl, 0.1 % SDS , and 0.5 mg/ml proteinase K, and incubated overnight for the samples to digest.	77%	AI
117	After incubation, DNA was extracted twice for 15 - 20 minutes with a 1:1 ratio of phenol and chloroform and again twice for 15 min utes with 24:1 volume of chloroform and isoamyl alcohol.	75%	AI
118	The aqueous phase was then precipitated with 2.5 volumes of 100% DNA grade ethanol in the presence of one-tenth volume of 3.0 M sodium acetate (pH 6.0).	74%	AI
119	The DNA pellets were washed with 70 % DNA-grade ethanol and dissolved in 0.1 ml saline sodium citrate (SSC) buffer.	68%	Mixed
120	The DNA concentration was measured at 260nm wavelength while purity was estimated at a ratio of A 260 /A 280 using an Ultraviolet (UV) Spectrophotometer (Model: Nanodrop 2000/2000c, Thermo-Scientific, USA) .	70%	Mixed
121	Experimental D esign	50%	Mixed
122	A total of 675 juveniles of Oreochromis niloticus (mean weight of 104.47 g and 5.47 cm length) were divided into five groups, with 135 juveniles per group (treatment , i.e., 45 fish per unit).	67%	Mixed
123	Different concentrations of SSC buffer-based DNA: 0 as control, 10, 20, 30, and 40 µg/µ l with a final volume of 0.1ml were injected into the dorsal somatic tissue of 45 fingerlings using a thermodynamic micro-syringe and needle in three replicates .	69%	Mixed
124	The fingerlings were then reared in a 3 x 2 x 1.2 m deep polyethylene fish pond at 7.5 fish/m 2 in three replicates arranged in a complete randomized design manner .	64%	Mixed
125	The fingerlings were fed with a 35 % crude protein commercial diet at 5% body weight for 3 months , t twice daily at 9:00 am and 3:00 pm.	64%	Mixed
126	Growth Performance of O. niloticus Containing Exogenous DNA	30%	Human
127	At the end of the three-month rearing period, the final weight (g), final length (cm), fish mortality, and quantity of feed applied were recorded.	72%	AI
128	We estimated the following growth indices for each treatment:	52%	Mixed
129	Weight gain (g) = W 2 – W 1, where W 2 and W 1 are the final and initial weights of the fish, respectively.	76%	AI
130	Percentage weight gain = W2 - W1 x 100, w1	67%	Mixed
131	Mean Daily Weight Gain (MDWG) in grams = W2-W1t, t = the culture period (days).	47%	Mixed
132	Specific Growth Rate (SGR % per day) = InlogW2-InlogW1t x 100, where In. logW 2 =	56%	Mixed
133	natural log of final weight, In.log W 1 = natural log of initial weight, and t = culture	48%	Mixed
134	period (Busacker et al ., 2012).	50%	Mixed
135	Feed conversion Ratio (FCR) = Dry weight of feed weight gain of fish	47%	Mixed
136	vi) Survival (%) = No. of fish survived. of fish stocked x 100.	42%	Mixed
137	Time series water quality was monitored during the study.	60%	Mixed
138	The temperature (o C), pH, electrical conductivity (µS /c m), and total dissolved solids (ppm) were measured using a Multifunction 4 - in -1 T emp./ EC / TDS /p H Meter (M odel : 9908, China) , and dissolved oxygen was recorded using a portable digital DO meter (Model: BLE-9100).	58%	Mixed
139	Proximate Composition of O. niloticus Improves Through DNA Transfer.	34%	Human
140	One hundred and f ifty (1 50) g of fish muscle from each treatment were collected and placed in an icepack containing ice flakes and shipped to the Animal Care quality control laboratory, Kano State, Nigeria, for proximate composition.	51%	Mixed
141	Before the proximate analysis, wet chemistry calibration against the AOAC standard was done.	42%	Mixed
142	To calibrate against standard methods (AOAC 2023 wet chemistry), 50g representative of fish samples containing L. niloticus DNA were collected and subjected to proximate composition analysis using standard wet chemistry methods as described in the AOAC International (2023) .	58%	Mixed
143	Moisture content was determined by oven drying at 105 °C until constant weight.	31%	Human
144	Crude protein was analysed using the Kjeldahl method, Crude lipid was measured by Soxhlet extraction with petroleum ether, Ash content was determined by incineration in a muffle furnace at 550 °C, and crude fibre was analysed using the enzymatic gravimetric method.	72%	AI
145	The same fish samples were scanned using the Near-Infrared Reflectance (NIR) multi-checker across the spectral range of 780–2500 nm.	66%	Mixed
146	Spectral data were processed using Partial Least Squares (PLS) regression to establish calibration equations by correlating NIR absorbance patterns with the AOAC-verified wet chemistry values.	64%	Mixed
147	Calibration models were validated with independent fish samples, and prediction accuracy was assessed using the Root Mean Squared Error of Prediction (RMSEP).	73%	AI
148	The proximate composition was conducted in triplicate using a digital Near Infrared (NIR) Multi-Checker (Model: 21MC11309A06, China) according to AOAC Internationa l (20 23) .	57%	Mixed
149	While metabolizable energy was estimated using Atwater conversion factors , the NRC (2011) formula:	30%	Human
150	w here CP = Crude Protein (%), EE = Ether Extract / Crude Fat (%), and NFE = Nitrogen Free Extract (%)	53%	Mixed
151	At the end of the experiment, 50 mg tissue from each treatment (including the control) in three replicates was collected after sedation according to the method described by Diyaware et al .	72%	AI
152	Three tissue samples were also collected from the donor fish (L. niloticus).	70%	Mixed
153	The samples were stored at −20°C until DNA extraction.	69%	Mixed
154	Genomic DNA was extracted from the tissues following the protocol described by Baradakci & Skibinski (1994).	70%	Mixed
155	Each tissue was crushed individually into smaller pieces using a laboratory pestle and mortar and homogenized using a tissue homogenizer.	76%	AI
156	The crushed tissues were then transferred into separate microcentrifuge tubes containing 50 mM Tris Bis buffer, 100 mM EDTA (pH 8.0), 100 mM NaCl, 0.1 % SDS, and 0.5 mg/ml proteinase K, and incubated overnight for the samples to digest.	78%	AI
157	After incubation, DNA was extracted twice for 15 - 20 minutes with a 1:1 ratio of phenol and chloroform and again twice for 15 min utes with 24:1 volume of chloroform and isoamyl alcohol.	75%	AI
158	The aqueous phase was then precipitated with 2.5 volumes of 100 % DNA grade ethanol in the presence of one-tenth volume of 3.0 M sodium acetate (pH 6.0).	74%	AI
159	DNA pellets were washed with 70 % DNA-grade ethanol and dissolved in 0.1 ml saline sodium citrate (SSC) buffer.	69%	Mixed
160	The DNA concentration was measured at 260nm wavelength, while purity was estimated at a ratio of A 260 /A 280 using an Ultraviolet (UV) Spectrophotometer (Model: Nanodrop 2000/2000c, Thermo-Scientific, USA).	71%	Mixed
161	Polymerase Chain Reaction (PCR) reactions were performed in 25 µL volumes containing 10 × PCR buffer, 2.0 mM $MgCl_2$, 0.2 mM dNTPs, 1.0 µM primer, 1 U Taq DNA polymerase, and 20–50 ng template DNA.	76%	AI
162	Three RAPD primers modified from Ogbuebunu & Awodiran (2017) were used for the PCR (Table 1).	49%	Mixed
163	All primers were amplified at an initial denaturation of 94 °C for 3 minutes, 40 cycles, denaturation temperature of 94 °C for 30 seconds, annealing temperature of 36 °C for 1 minute, extension at 72 °C for 1 minute, final extension at 72 °C for 10 minutes, and holding temperature of 4 °C.	79%	AI
164	Table 1: Random Amplified Polymorphic DNA (RAPD) Primer Sequences	74%	AI
165	Gel E lectrophoresis	50%	Mixed
166	Polymerase chain reaction (PCR) products were resolved on 1.5 % agarose gels at a voltage of 70V for 40-50 minutes, stained with ethidium bromide.	75%	AI
167	The gels were visualized under gel documentation Ultraviolet (UV) light plate and photographe d.	27%	Human
168	Banding patterns were compared between the fish that recieved the DNA and the control fish.	65%	Mixed
169	The presence of unique bands in injected fish was interpreted as evidence of foreign DNA integration.	45%	Mixed

#	Sentence	AI Score	Label
170	Scoring , A nalysis of RAPDs , and Estimation of the Molecular Weight	45%	Mixed
171	The genotypes were determined by recording the presence (1) or absence (0) of bands in the RAPD profiles .	72%	AI
172	The dendrogram was then constructed using Euclidean c luster analysis.	67%	Mixed
173	The molecular weights of RAPD fragments were estimated according to the method described by Sambrook & Russell (2001) by comparing their electrophoretic mobility with that of a standard DNA ladder.	73%	AI
174	Migration distances (cm) of the marker bands were measured from the wells to the center of each band, and a standard curve was constructed by plotting the logarithm ($\log_{10}$) of the known fragment sizes (bp) against their migration distances.	74%	AI
175	The sizes of RAPD bands were then interpolated from this curve.	40%	Human
176	Data A nalysis	50%	Mixed
177	Data obtained on growth performance indices, proximate composition, and water quality were subjected to a O ne-way A nalysis of V ariance (ANOVA) .	38%	Human
178	The differences between the means were determined using Tukey's Least Significant Difference (LSD) at 95% confidence level (p <0.05) with the aid of Statistix 8.0 .	76%	AI
179	The RAPD fingerprints generated for all samples were scored using a Gel analyzer.	40%	Human
180	The genetic diversity was determined using GenAlex (Peakall and Smouse, 2012) .	23%	Human
181	Phylogenetic trees to check genetic distance were constructed using Nei's (1972) Unweighted Pair Group Method with Arithmetic Mean (UPGMA) Euclidean Cluster analysis with the aid of PAST 4.03.	60%	Mixed
182	Table 1 shows the time series water quality parameters observed during the study.	70%	Mixed
183	D issolved O xygen (DO) ranged from 6 . 2 0 to 6. 4 8 mg/l in May, 641- 6.66 mg/l in June , 640- 6.80 mg/l in July, and 6.15- 6.80 in August.	75%	AI
184	While the temperature ranged between 30.80- 32.20, 28.70- 29.80, 28.30-29.80, and 28.60-29.33 °C in May, June, July, and August, respectively.	78%	AI
185	No significant variance (p>0.05) was observed between the DO in May, June, and July, except in August, where significant differences (p>0.05) were observed between the DO values among the rearing tanks.	78%	AI
186	The pH values in the culture media during May were between 7.48 and 8.34, in May, 8-8.62 in June, 8-8.90 in July, and 7-8.01 in August.	77%	AI
187	The TDS were between 93.0 - 125.33 (ppm) in May, 150.33 – 162.33 (ppm) in June, 150 – 152 in July, while in August the TDS were between 107 - 127.67 (ppm). and EC ranged between 186-251.33 (µs/cm) in May 301- 308.	75%	AI
188	(µs/cm) June, while in July and August the EC were between 255-305 and 212 - 257.33 µ S /cm, respectively.	53%	Mixed
189	The variations in the dissolved oxygen contents in the culture medium might have affected the growth performance among treatment groups and the survival, despite the fact that all the water quality parameters observed were within the recommended range for Tilapia culture (Boyd and Tucker, 1998).	74%	AI
190	Table 2 : Time Series w ater quality parameters observed during the study	25%	Human
191	Growth P erformance of O . niloticus Containing E xogenous Fish DNA	7%	Human
192	Table 2 shows growth performance of O. niloticus injected with L. niloticus DNA.	63%	Mixed
193	Fish injected with 40 µg/µl L. niloticus DNA recorded significantly ($p < 0.05$) higher final weight (751.90 ± 18.50 g), weight gain (650.02 ± 19.25 g), average daily weight gain (5.41 ± 0.16 g/day), percentage weight gain (432.96 ± 10.34%), and specific growth rate (2.86 ± 0.01%/day) compared to other treatments.	75%	AI
194	Our results are in agreement with El-Zaeem (2004), El-Zaeem and Assem (2004), Hemeida et al .	71%	Mixed
195	(2004), and Assem and El-Zaeem (2005), who found enhanced growth performance in O. niloticus and T. zillii (Coptodon zilli) injected with 40 µg/µl shark DNA.	55%	Mixed
196	Similarly, El-Zaeem et al .	50%	Mixed
197	(2011, 2012a) observed higher body weight and specific growth rate in O. niloticus injected with Seabream and Artemia salina DNA.	30%	Human
198	El-Zaeem (2012b) also reported improvements in growth performance of grey mullet fingerlings injected with shark DNA.	48%	Mixed
199	Kusa et al .	50%	Mixed
200	(2025) and Thabet et al .	65%	Mixed
201	(2025) reported improved final weight, mean daily weight gain, and specific growth in O. niloticus injected with 40 µg/µL Heterotis niloticus DNA and Salmon DNA, respectively.	51%	Mixed
202	The final length w ere statistically (p>0.05) similar across treatments in this experiment .	63%	Mixed
203	Table 3 : Growth Performance of O . niloticus Containing E xogenous Fish DNA	8%	Human
204	1.37± 0.01 ab	50%	Mixed
205	Means with the same superscript in the same row are not significantly different (p>0.05).	72%	AI
206	Key : IW = Initial weight, FW = Final weight, IL= initial length, final length, WG = Weight gain, ADWG = Average daily weight gain, SGR = Specific growth rate, FCR = Feed conversion ratio.	71%	Mixed
207	Abd El Hamied (2009) and Elwan (2009) observed improved growth performance, feed utilization, and other quantitative traits in O. niloticus injected with foreign DNA.	58%	Mixed
208	Higher growth indices in fish injected with higher DNA may indicate transient expression or epigenetic effects, as suggested by Konstantinidis et al .	65%	Mixed
209	Feed Conversion Ratio (FCR) was significantly (p<0.05) higher (1.46±0.07) , in fish injected with 20 (µg/µL) DNA.	70%	Mixed
210	There were no significant variations (p<0.05) were observed in the FCR of fish injected with 10 and 30 µg/µL) DNA comapred to those injected with 20 µg/µL .	66%	Mixed
211	Significant variations (p>0.05) were observed in FCR of fish injected with 40 (µg/µL) DNA compared to those injected with 10-30 (µg/µL) L. niloticus DNA and control fish.	73%	AI
212	The FCR of O. niloticus injected with L. niloticus DNA in this study was lower than 1.88 and 1.89 reported by El-Zaeem (201 2) for grey mullets (Mugil cephalus) injected with Shark DNA in to .	55%	Mixed
213	The FCR was also lower than 1.83 reported by El Zaeem et al.	15%	Human
214	(2023) in Coptodon zilli following injection with shark DNA and 1.5 reported by Krivins (2024) for O. niloticus fed a commercial diet.	53%	Mixed
215	The variation may be due to differences in the fish species , rearing conditions and the sources of the DNA , and the degree of domestication selection the species must have undergone .	74%	AI
216	The lower FCR observed in this study may also be due to the trade-off between growth acceleration and nutrient utilization.	70%	Mixed
217	This trade-off between growth acceleration and nutrient utilization efficiency has been reported in several studies on transgenic and genetically improved fish.	72%	AI
218	El-Zaeem et al .	50%	Mixed
219	(2009) observed that shark DNA injected into red tilapia improved growth and feed utilization, but optimal efficiency was achieved under moderate dietary protein levels, suggesting that excessive stimulation may compromise metabolic balance.	59%	Mixed
220	Rahman et al .	50%	Mixed
221	(2001) confirmed that transgenic tilapia are also more efficient in utilizing protein and energy.	65%	Mixed
222	The survival of O. niloticus exposed to varying concentrations of L. niloticus DNA (0–40 µg/µL) ranged between 23.33% and 27.67%, with no significant differences (p>0.05) among treatments.	75%	AI
223	This indicates that DNA concentration did not affect survival.	65%	Mixed
224	This is consistent with earlier reports that tilapia tolerate foreign DNA exposure without major mortality effects (Rahman et al ., 1998; El-Zaeem, 2012; Konstantinidis et al ., 2020).	58%	Mixed
225	The relatively low overall survival likely reflects environmental or handling stress, which has been shown to exert a stronger influence on tilapia survival than genetic manipulation (Omweno, 2023; Ahmed, 2023).	72%	AI
226	The Growth Pattern of O. niloticus, Containing Exogenous Fish DNA	7%	Human
227	The growth pattern of O. niloticus , containing exogenous fish DNA, is illustrated in Figure 2.	65%	Mixed
228	A significant (p<0.05) progressive growth increase was observed with the increase in DNA concentration throughout the study.	77%	AI
229	The L. niloticus DNA transfer had a dose-dependent relationship (Fig. 1).	32%	Human
230	The progressive growth pattern may indicate that fish containing high concentrations of DNA might have efficiently utilized the diet given to them.	54%	Mixed
231	Fu et al .	50%	Mixed
232	(1998) reported that transgenics were more efficient in utilizing dietary protein compared to their non-transgenic siblings.	74%	AI
233	Rahman et al .	50%	Mixed
234	(2001) confirmed that transgenic tilapia are also more efficient in utilizing protein and energy.	65%	Mixed
235	Fig ure . 2: Growth pattern of O. niloticus containing exogenous fish DNA	35%	Human
236	Proximate Composition of O. niloticus Containing Exogenous Fish DNA	48%	Mixed
237	Table 3 shows the p roximate composition of O . niloticus containing exogenous fish DNA.	63%	Mixed
238	Crude protein (CP) content increased significantly (p<0.05) with an increase in the DNA concentration.	73%	AI
239	A higher CP of 39.05 % was observed in fish injected with 40 µg/µl of DNA, followed by 36.36 % CP in fish injected with 30 µg/µl of DNA.	75%	AI
240	A lower CP of 27.90 % was observed in the control group , suggesti ng that the foreign DNA might have enhanced muscle protein synthesis in the Nile Tilapia.	61%	Mixed
241	The protein contents observed in this study were higher than 14.62 % CP observed in red belly tilapia (Coptodon zilli) injected with Shark DNA, as observed by El-Zaeem et al .	53%	Mixed
242	(2023), and 11.32, 13.10, and 9.80 % in O . niloticus , O . aureus , and their hybrids, respectively, as documented by El-Hawarry (2012).	72%	AI
243	Suwannatrai et al .	50%	Mixed
244	(2023) reported 14.27 % crude protein of O. niloticus from Sakon Nakhon province, Thailand, while Kumara et al.	45%	Mixed
245	(2020) noticed 7.85 % crude protein in O. niloticus from Sri Lanka.	27%	Human
246	The variation in the crude protein level may be due to the differences in the fish species, the source of the DNA, and the age of the fish.	77%	AI
247	However, Mukti et al .	50%	Mixed
248	(2020) reported 85.70 and 87.00 % crude protein in triploid male and female O. niloticus , respectively.	60%	Mixed
249	The greater variation observed in the crude protein levels of the sterile Tilapia compared to the tilapia containing foreign DNA could be due to the complete utilization of feed for growth only by the fish, rather than growth and reproduction as occurs in the fertile Tilapia containing foreign DNA.	76%	AI
250	Martinez et al .	50%	Mixed
251	(2000) reported an increased protein synthesis and growth rate concomitant with enhanced glycolysis and oxidation of amino acids in juvenile O. niloticus containing cDNA growth hormone .	73%	AI
252	The increase in crude protein level observed in the fish injected with 40 µg/µl L. niloticus DNA may be due to the effective conversion of sparing nutrients from fish feed by the fish.	61%	Mixed
253	A similar trend was also reported by Yuvarajan et al .	66%	Mixed
254	(2019) in Genetically Improved Farmed Tilapia (GIFT), which recorded a remarkable increment in protein and lipid contents.	63%	Mixed

#	Sentence	AI Score	Label
255	Such an increase implies improved nutritional quality, which is important for Tilapia aquaculture profitability (Cebeci et al ., 2020) and improves the public health of consumers.	72%	AI
256	Abd El Hamied (2009) and Elwan (2009) reported HIGHER body composition, in O. niloticus injected with foreign DNA	53%	Mixed
257	Table 4 : Proximate Composition of O . niloticus Containing Ex ogenous Fish DNA.	45%	Mixed
258	Means in the same column having similar superscripts are not significantly different (p>0.05).	70%	Mixed
259	Key: CP = Crude protein, EE = Ether extract, CF = Crude fiber, ME = Metabolizable energy.	71%	Mixed
260	Ash levels showed no significant variation (p>0.05) among the entire treatments.	66%	Mixed
261	This suggests that DNA transfer had minimal effect on mineral content.	60%	Mixed
262	The significance of ash contents among the treatments aligns with studies that ash is less sensitive to genetic or dietary manipulation (Abdel-Tawwab et al ., 2010).	47%	Mixed
263	The ash contents observed in this study are lower than 1.36 % for O. niloticus and hybrid red tilapia by Olopade et al .	59%	Mixed
264	(2016) in Nigeria and 2.27±0.34 reported by Kamruzzaman et al . 2018) for O. niloticus collected from Mymensingh Messua Baza of Bangladesh.	29%	Human
265	Ether Extract (EE) was significantly (p<0.05) higher (13.12±0.3 and 12.47±0.02 %) in fish treated with 10 and 40 µg/µl DNA, respectively .	72%	AI
266	The lowest EE (9.16±0.03 %) value was observed in fish containing 30 µg/µl DNA concentration.	51%	Mixed
267	Generally, there were significant variations (p<0.05) among the mean values of the EE across all the treatments.	72%	AI
268	The ether extract content, which reflects the lipid concentration in fish, showed noticeable (p<0.05) variations across the treatments.	67%	Mixed
269	High lipid levels, especially in fish containing 10 and 40 µg/µl DNA, may indicate altered lipid metabolism probabbly due to foreign DNA expression.	56%	Mixed
270	The observed (9 - 13 %) EE may indicate that the foreign DNA could have influenced lipid metabolism in the Nile tilapia.	58%	Mixed
271	Genetic modification, particularly through DNA/gene transfer, is known to impact lipid regulation pathways.	71%	Mixed
272	A similar trend was observed in transgenic mice containing silencing genes (SREBP-1c and PPARα), which significantly changes lipid synthesis and fatty acid oxidation (Horton et al ., 2002).	71%	Mixed
273	Devlin et al .	50%	Mixed
274	(2001) demonstrated that transgenic salmon exhibited increased lipid accumulation due to enhanced growth signals, suggesting that similar mechanisms might explain the ether extract changes observed in this study.	70%	Mixed
275	Therefore, while moderate increases in EE could enhance nutritional value, careful optimization is required to balance consumer health concerns and product quality.	68%	Mixed
276	Similarly, higher ether extract in the fish containing the foreign DNA may result in beneficial fatty acids such as Omega-3, which can enhance the fish's health value as suggested by Tocher (2003).	68%	Mixed
277	Crude fibre was observed to be significantly (p<0.05) h igher (1.64±0.03%) in fish injected with 10 µg/µl DNA compared to the entire treatment.	56%	Mixed
278	The lowest (0.92±0.01%) crude fibre content was observed in the group injected with 40 µg/µl DNA.	57%	Mixed
279	The crude fibre observed in this study is higher than 0.98 % reported by Yuvarajan et al .	62%	Mixed
280	(2019) in Genetically Improved Farmed Tilapia (GIFT) and 0.54 and 0.59 % reported by Olapode et al .	65%	Mixed
281	(2016) for O. niloticus and hybrid red tilapia, respectively.	49%	Mixed
282	The variation in the fibre content may be due to strain variation (GIFT, normal tilapia, and the hybrids).	60%	Mixed
283	Although fish naturally contain low fiber, these changes may reflect alterations in gut microbiota or feed digestion due to genetic influence.	64%	Mixed
284	Bolawa et al .	50%	Mixed
285	(2011) reported very low crude fibre, while Otene et al.	6%	Human
286	(2024) found fibre values consistently to be below 1 %, emphasizing that fish muscle is not a source of dietary fibre.	56%	Mixed
287	Moisture content increases with an increase in DNA concentration, with the significantly (p<0.05) highest (63.94%) mean value in fish that received 40 µg/µl DNA.	63%	Mixed
288	This trend suggests a positive correlation between DNA concentration and moisture retention in fish.	69%	Mixed
289	The higher moisture contents observed in this are lower than 81.39 and 80.09 % observed by Olopade et al .	45%	Mixed
290	(2016) for O. niloticus and hybrids of red Tilapia, respectively.	32%	Human
291	El-Hawarry (2012) reported 79.09, 79.12, and 80.45 % moisture contents of fillets of O . niloticus , O . aureus , and their hybrids.	69%	Mixed
292	The high moisture content observed in fish injected with a higher dosage of DNA may indicate that the muscle tissue of the fish retains more water, which could affect texture, shelf life, and susceptibility to spoilage (perishability).	71%	Mixed
293	Wang and Zheng (2025) emphasize that enzymatic autolysis, lipid oxidation, and microbial growth are the main drivers of fish spoilage, all of which are facilitated by high moisture levels in the fish .	73%	AI
294	Elevated water retention may be associated with changes in muscle plasticity and gene regulation, as recent studies highlight the role of DNA methylation and microRNAs in modulating muscle growth and water-binding properties in fish (Koganti et al ., 2020) .	76%	AI
295	Significant variation (p<0.05) was observed between the mean moisture contents of the fish treated with 10 µg/µl DNA compared to the entire treatments.	66%	Mixed
296	However, no significant variations were observed among the moisture contents of fish treated with 0, 20, and 30 µg/µl DNA.	68%	Mixed
297	M etabolizable Energy	50%	Mixed
298	Metabolizable energy wa s significantly higher (3474.10±91.36 Kcal) in fish treated with 40 µg/µl DNA, followed by (2970 ± 3.0 K cal) in fish treated with 30 µg/µl DNA .	64%	Mixed
299	The increase in the Metabolizable energy (ME) with an increase in concentration of the DNA may indicate improved nutrient density and energy utilization, possibly reflecting metabolic shifts which might have been influenced by the presence o f foreign DNA sequences related to growth or feed efficiency.	68%	Mixed
300	According to Thabet et al.	50%	Mixed
301	(2025), foreign DNA can upregulate metabolic efficiency, thereby increasing metabolizable energy concentration.	57%	Mixed
302	Konnert et al .	50%	Mixed
303	(2022) opined that high ME indicates efficient nutrient conversion in the fish, which translates to better protein and fat availability for human consumption.	58%	Mixed
304	The DNA purity used in this study was 1.76 ng/µL at A260/A280 and 1.09 at A260/A230.	70%	Mixed
305	Fig . 3 is the RAPD gel representative of O. niloticus injected with L.niloticus DNA.	57%	Mixed
306	Gel electrophoresis revealed distinct banding patterns: the control fish had 5 bands, while fish injected with 10, 20, 30, and 40 µg/µL had 7, 6, 8, and 9 bands, respectively, suggesting probable differential integration or transient expression of L . niloticus DNA fragments among the treated fish.	74%	AI
307	The donor fish DNA fragment wa s approximately 300 bp in size, based on its position relative to the 250 bp and 500 bp ladder bands.	61%	Mixed
308	Fig. 3: Gel representative of the DNA fingerprint of O . niloticus containing L . niloticus DNA	73%	AI
309	Out of five loci scored, four were polymorphic, corresponding to 80% polymorphism .	68%	Mixed
310	The 80% polymorphism observed in this study may be an indicator of genetic variability likely induced by the injected L . niloticus DNA.	68%	Mixed
311	The observed polymorphism in RAPD profile may reflect genetic differences associated with introduction of L. niloticus DNA (Williams et al ., 1990).	57%	Mixed
312	The 80 % polymorphysim obser v ed in this study is higher than 50-70% for healthy fish populations as suggested by Ali et al.	19%	Human
313	However, the high polymorphism observed in this study is less than 98.9% observed in Genetically Improved Farmed Tilapia (GIFT) reported by Oliveira et al .	74%	AI
314	(2011) using RAPD.	50%	Mixed
315	The variation could be due to differences in the genetic improvement method; GIFT tilapia were improved through selection, which has high heritability, while DNA injected into the muscle is taken up by muscle cells and may be expressed locally , hence the effect may be somatic and transient (Heppell and Davis, 2000).	64%	Mixed
316	The presence of polymorphic loci may suggest introgression of L. niloticus DNA.	72%	AI
317	While genetic variability can enhance resilience to environmental stress and disease (Weising et al., 2005), these findings align with earlier reports by Sambrook and Russell (2001) that RAPD analysis is effective in revealing high levels of polymorphism in fish .	68%	Mixed
318	The exhibition of different banding patterns may indicate genetic variation among the fish.	50%	Mixed
319	The 250 bp band appears to correlate with increasing DNA concentration in O.niloticus , which may suggest a gene or DNA fragment silently or transiently expressed or integrated more at higher concentration ADDIN EN.CITE <EndNote><Cite><Author>Kusa</Author><Year>2026</Year><RecNum>851</RecNum><DisplayText>(Kusa et al., 2026)</DisplayText><record><rec-number>851</rec-number><foreign-keys><key app="EN" db-id="pda9x2rek52fr8e0s2q5tfeq05ae29dtztva" timestamp="1773666915">851</key></foreign-keys><ref-type name="Journal Article">17</ref-type><contributors><authors><author>Kusa, Thami</author><author>Diyaware, Mohammed Yakubu</author><author>Suleiman, Sa'adu Bala</author><author>Aliyu, Mohammed</author><author>Mohammed, Zanna Barde</author><author>Ajibike, Abdulhakeem Biola</author><author>Popoola, Omoniyi Michael</author><author>Haruna, Mohammed Yakubu</author></authors></contributors><titles><title>Growth response and some spawning indices of Nile Tilapia (Oreochromis niloticus, Linnaeus 1758) containing piscine DNA</title><secondary-title>The Journal of Basic and Applied Zoology</secondary-title></titles><periodical><full-title>The Journal of Basic and Applied Zoology</full-title></periodical><volume>87</volume><number>1</number><dates><year>2026</year></dates><isbn>2090-990X</isbn><urls></urls><electronic-resource-num>10.1186/s41936-026-00547-9</electronic-resource-num></record></Cite></EndNote> (Kusa et al. , 2026) .	76%	AI
320	The 500 bp band, observed in fish injected with 30 and 40 µg/µL, might be a unique RAPD fragment only expressed or detectable at higher DNA concentrations, and is possibly a dose-sensitive gene or regulatory element activated at higher DNA loads.	56%	Mixed
321	The presence of distinct bands in the injected fish and their absence in controls may indicated transient DNA expression on DNA damage or stress cause d by the foreign DNA.	28%	Human
322	Intramuscular DNA delivery in fish is known to produce temporary expression of foreign genes.	64%	Mixed
323	For instance, DNA vaccine studies in salmon and tilapia show that injected DNA can be transcribed in muscle fibers for a limited period before degradation (Heppell and Davis, 2000).	69%	Mixed
324	Foreign DNA can activate DNA repair pathways in muscle cells and s keletal muscle exposed to exogenous DNA may undergo fragmentation due to nuclease activity and repair enzyme activation (Dey et al ., 2023).	68%	Mixed
325	T he distinct bands may be a stress response to the injected foreign DNA.	37%	Human
326	According to Petitjean et al .	74%	AI
327	(2019) and Yuan et al .	33%	Human
328	(2025) , s tress in fish alters gene expression and DNA stability .	5%	Human
329	The unique fragments may therefore reflect stress induced molecular changes in tilapia muscle.	23%	Human
330	Assem and El-Zaeem (2005) reported integration of Shark DNA into the genome of Tilapia zilli (Coptodon zill ii) after direct injection.	53%	Mixed
331	In a similar vein, El-Zaeem et al .	71%	Mixed
332	(2011) reported the random integration of sea bream and Artemia DNA into O. niloticus genomes.	43%	Mixed
333	They claimed that the integrations could be a functional or a silent integration, as suggested by Yaping et al .	64%	Mixed
334	Fujimura and Kocher (2011) demonstrated efficient transgenesis in O. niloticus using the Tol2 transposon system, achieving approximately 30% germline transmission and strong Green Fluorescent Protein (GFP) expression.	72%	AI
335	Similarly, Olabode et al .	50%	Mixed

#	Sentence	AI Score	Label
336	(2014) reported successful integration of growth hormone genes using Tol2-mediated microinjection, with PCR confirmation and enhanced growth in transgenic tilapia.	56%	Mixed
337	The L. niloticus DNA injected into O. niloticus may have induced genomic alterations or changes in RAPD amplification patterns, resulting in observed polymorphic RAPD profiles.	61%	Mixed
338	Zhang et al .	50%	Mixed
339	(1994) demonstrated that RAPD analysis detected genomic changes in tilapia following microinjection of foreign DNA, with altered banding patterns compared to non-injected controls.	72%	AI
340	RADP B anding and Fragment size of O. niloticus containing L. niloticus DNA	42%	Mixed
341	Table 5 shows the mean m olecular w eights of DNA b ands in O. niloticus treated with L. niloticus DNA.	60%	Mixed
342	Electrophoresis of O. niloticus containing L. niloticus DNA revealed DNA fragments between 430 and 540 bp, while the donor fish had an average of 565 bp.	74%	AI
343	Lower concentrations (0 µg/µL) were associated with the smaller fragments (430 bp), while moderate doses (10–20 µg/µL) yielded larger fragments (502–540 bp).	73%	AI
344	At higher concentrations (30–40 µg/µL), fragment sizes decreased slightly (452–475 bp), suggesting possible saturation or degradation effects.	55%	Mixed
345	These results align with the principle that DNA migration is inversely related to fragment size (Lee et al ., 2012).	71%	Mixed
346	The clustering of fragments near the donor reference (565 bp) suggests that injected DNA was maintained long enough to be detected, consistent with transient expression of foreign DNA (Li et al ., 2019).	69%	Mixed
347	While Variability across concentrations may reflect epigenetic regulation, as mechanisms like DNA methylation and histone modification can silence or exert influence on injected DNA activities (Bird, 2007; Zhang et al ., 2020).	61%	Mixed
348	In tilapia, epigenetic responses to exogenous DNA have been shown to influence fragment stability and retention (Akinwale et al ., 2023).	70%	Mixed
349	Thus, the observed patterns highlight the interplay between transient expression and epigenetic control in shaping the fate of donor DNA within host genomes.	72%	AI
350	Table 5: Mean Molecular Weights of DNA Bands in O. niloticus Injected with L. niloticus DNA	66%	Mixed
351	Genetic Similarity I ndices	50%	Mixed
352	The dendrogram generated from gel electrophoresis banding profiles using UPGMA (F ig . 4) cluster revealed distinct groupings among fish that received L . niloticus DNA.	59%	Mixed
353	The control fish (0 µg/µL of DNA) clustered separately from the donor fish, indicating genetic dissimilarity from their sibling that received DNA.	51%	Mixed
354	In contrast, samples that received 10 to 20 µg/µL DNA showed progressive clustering toward L . niloticus , suggesting a dose-dependent assimilation of L . niloticus genetic material.	72%	AI
355	Oreochromis niloticus injected with 30 and 40 µg/µL DNA formed a close cluster, indicating close similarity.	24%	Human
356	The donor fish (L . niloticus) clustered separately .	8%	Human
357	The O . niloticus injected 10 µg/µL exhibited moderate bootstrap, indicating that it is closer to O . niloticus than those injected with 30 and 40 µg/µL DNA .	66%	Mixed
358	Fig . 4 : Phylogenetic tree based on Nei's (1972) standard genetic distances using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) method generated from RAPD data.	67%	Mixed
359	Key : DFish = Donor fish (Lates niloticus).	6%	Human
360	Overall, the dendrogram supports the hypothesis that the increasing DNA concentration enhances slight genetic similarity to the source organism, with 30 – 40 µg/µL representing a potential threshold for effective transient transformation.	59%	Mixed
361	This pattern of closer cluster formation of fish that recieved higher DNA concentration implies that higher DNA concentrations could have enhanced genomic integration or expression, which is consistent with previous findings in transgenic fish by Zhang et al .	72%	AI
362	(2010) and Agha et al .	68%	Mixed
363	The moderate bootstrap exhibited by fish injected with DNA closer to the donor fish, (L. niloticus) , suggests partial uptake or variability in transformation efficiency.	37%	Human
364	These findings align with earlier reports by Sneath & Sokal (1973), Rohlf (2000), Fu et al .	66%	Mixed
365	(2021), and Georgieva (2022) that hierarchical clustering can effectively resolve genetic relationships in electrophoretic data.	75%	AI
366	This study revealed that fragmented DNA materials from Lates niloticus may potentially improve growth in Oreochromis niloticus .	55%	Mixed
367	Fragment of L. niloticus DNA transiently integrated into the O. niloticus genome.	69%	Mixed
368	The DNA of L. niloticus has altered the proximate composition of Nile tilapia, especially by enhancing protein content and metabolizable energy.	64%	Mixed
369	These changes could offer nutritional, economic, and production benefits in Tilapia aquaculture, though further investigation into safety, long-term performance, and consumer acceptance is essential.	72%	AI
370	Although the present study demonstrates that injection of Nile perch DNA can enhance growth and proximate composition in Nile tilapia, several limitations may restrict its direct application to aquaculture.	70%	Mixed
371	The injection method is labor-intensive and impractical for large-scale farming, while handling stress and mortality may reduce survival under commercial conditions.	68%	Mixed
372	Furthermore, the stability of DNA integration and long-term inheritance is yet to be confirmed, raising questions about the sustainability of the observed improvements.	75%	AI
373	Economic feasibility, food safety, and consumer acceptance of fish containing exogenous DNA also remain unresolved.	62%	Mixed
374	Finally, comparative evaluation against established improvement methods such as selective breeding or hormonal sex reversal was not undertaken.	55%	Mixed
375	These limitations highlight the need for further study before Lates niloticus DNA transfer can be considered .	58%	Mixed
376	T he integration of DNA be confirmed the DNA integration through qPCR or Insitu-hybridization as a viable strategy for aquaculture are yet to be confirmed .	62%	Mixed
377	The experiment was conducted following the approval of the Health Research Ethics Committee (HREC) No.	79%	AI
378	UNIMAID/HREC/VOL.1/2022/04 guiding the use of animals in scientific research at the University of Maiduguri, Nigeria, and in compliance with Nigeria's National Biosafety Management Procedures on	67%	Mixed
379	The authors are grateful to the Tertiary Education Trust Fund (TET Fund), Nigeria, for providing the necessary funds through the 2021 National Research Fund (NRF) for the research.	77%	AI
380	We are thankful to the Northeast Biotechnology Centre, University of Maiduguri, Nigeria, for allowing us to use their facilities and staff.	74%	AI
381	We wish to acknowledge the assistance of Prof.	73%	AI
382	Samy Yehya El-Zaeem of the Animal and Fish Production Department, Alexandria University, Egypt.	55%	Mixed
383	The advice of Dr.	50%	Mixed
384	Silvanus Nwafili Anene of the Department of Fisheries and Aquaculture, University of Port Harcourt, Nigeria, is highly acknowledged.	68%	Mixed
385	The contributions of Prof.	50%	Mixed
386	Micheal Omoniyi Popoola, of the Department of Fisheries and Aquaculture Technology, Federal University of Technology, Akure, are also acknowledged.	67%	Mixed
387	Conceptualized, designed the methodology, supervised, and wrote the manuscript text.	62%	Mixed
388	A.M.W. ran the experiment.	50%	Mixed
389	Z.B.M. and M.Z.H. collected the data and monitored the water quality parameters in the culture tank.	76%	AI
390	M.B. and M.B.A. conducted the laboratory work.	77%	AI
391	A.B.A. did the Gel scoring and data analysis.	57%	Mixed
392	L.U.C., D.M.U., and M.I.S. proofread the manuscript.	78%	AI
393	All authors read, edited, and approved the final manuscript.	73%	AI
394	The research was funded by the Tertiary Education Trust Fund (TETFund), Nigeria, under the 2021 National Research Fund (NRF) grant number TETFUND/DR&D-CE/NRF 2021	71%	Mixed
395	Conflicting Interests statement	50%	Mixed
396	The authors declare that they have no competing interests.	76%	AI
397	Abatcha, I., Mustapha, A., and Barkindo, A.	78%	AI
398	Comprehensive analysis of rainfall variability in urban Maiduguri, Nigeria: Implications for climate resilience and sustainable development.	74%	AI
399	International Journal of Environment and Climate Change , 14(3), 149-159.	77%	AI
400	Abd El-Hamied, A.M.L.	50%	Mixed
401	Studies on the Induction of Genetically Modified Blue Tilapia (Oreochromis aureus).	68%	Mixed
402	Thesis , Faculty of Agriculture (Saba-Bacha), Alexandria.	24%	Human
403	University of Alexandria, Egypt.	50%	Mixed
404	Abdel-Tawwab, M., Ahmad, M.	50%	Mixed
405	H., Khattab, Y.	50%	Mixed
406	E., and Shalaby, A.	50%	Mixed
407	Effect of Dietary Protein Levels on Growth Performance and Protein Utilization in Nile tilapia (Oreochromis niloticus).	68%	Mixed
408	Aquaculture Research , 41 (8), 1265–1271.	61%	Mixed
409	Ahmed, I., Jan, K., Fatma, S., & Dawood, M.	79%	AI
410	Muscle proximate composition of various food fish species and their nutritional significance: A review.	49%	Mixed
411	Journal of Animal Physiology and Animal Nutrition, 106 (5), 13711. https://doi.org/10.1111/jpn.13711 .	77%	AI
412	Akinwale, M., et al.	50%	Mixed
413	Epigenetic responses to foreign DNA in tilapia species .	66%	Mixed
414	Journal of Fish Biology , 102(4), 765–774.	66%	Mixed
415	Ali, B.A., Ahmed, M.M.M., and El-Zaeem, S.Y.	82%	AI
416	Application of RAPD markers in fish: Part I—Some genera (Tilapia, Sarotherodon, and Oreochromis) and Species (Oreochromis aureus and Oreochromis niloticus) of Tilapia.	71%	Mixed
417	International Journal of Biotechnology , 6 (1), 86–93. https://doi.org/10.1504/IJBT.2004.004615 .	78%	AI
418	Ali , B.	50%	Mixed
419	A., Huang , T., Qin , D., and Wang , X.	75%	AI
420	A Review of Random Amplified Polymorphic DNA (RAPD) Markers in Fish Research.	64%	Mixed
421	Reviews in Fish Biology and Fisheries , 14:443–453.	26%	Human
422	Anderson, E.D., Mourich, D.V., Fahrenkrug, S.C., LaPatra, S., Shepherd, J., and Leong, J.A.	82%	AI

#	Sentence	AI Score	Label
423	Gene expression in rainbow trout (Oncorhynchus mykiss) following Intramuscular Injection of DNA.	75%	AI
424	Molecular Marine Biology and Biotechnology 5, 105–113.	66%	Mixed
425	Andri, I., Zairin, M., and Harton, A.	72%	AI
426	The Effectiveness of Bull Testes Meal Extract on Sex Reversal of Nile Tilapia, Oreochromis niloticus by Immersion Technique.	47%	Mixed
427	MT-Fisheries IPB University Scientific Repository . 3076]. http://repository.ipb.ac.id/handle/123456789/56745	68%	Mixed
428	Official methods of analysis of AOAC International (22nd ed.).	46%	Mixed
429	AOAC International. https://www.aoac.org	50%	Mixed
430	S. and El-Zaeem, S.	50%	Mixed
431	Application of Biotechnology in Fish Breeding.	63%	Mixed
432	II: Production of Highly Immune Genetically Modified Redbelly Tilapia, Tilapia zilli .	71%	Mixed
433	African Journal of Biotechnology 4 (5), 449-459.	78%	AI
434	Baradakci, F. and Skibinski, D.	73%	AI
435	Application of the RAPD Technique in Tilapia Fish: Species and Subspecies Identification.	60%	Mixed
436	Heredity , 73, 117-123.	50%	Mixed
437	Transgenic Fish and Its Progress ", Futuristic Trends in Biotechnology Volume 3 Book 6, IIP Series 3:77-86. https://www.doi.org/10.58532/V3BJBT6P4CH2 .	68%	Mixed
438	Perceptions of epigenetics .	50%	Mixed
439	Nature , 447 (7143), 396–398.	13%	Human
440	Aspects of the Application of Gene Transfer as a Breeding Technique for Farm Animals.	64%	Mixed
441	Zentralbl ., 108, 1-8.	50%	Mixed
442	Cebeci, A., İhan Aydın, I., and Goddard, A.	72%	AI
443	Bigger, Stronger, Better: Fish Transgenesis Applications and Methods .	54%	Mixed
444	Biotechnology Studies 29 (2), 85-97. http://doi.org/10.38042/biost.2020.29.02.05 .	77%	AI
445	Chatakondi, N., Lovell, R.T., Duncan, P.L., Hayat, M., Chen, T.T., Powers, D.A., Weete, J.D., Cummins, K., and Dunham, R.A.	82%	AI
446	Body Composition of Transgenic Common Carp (Cyprinus carpio) Containing Rainbow Trout Growth Hormone Gene.	64%	Mixed
447	Aquaculture 138, 99-109.	50%	Mixed
448	Chukwu, J., Diyaware, M.	50%	Mixed
449	Y. and Ude, E.	50%	Mixed
450	Evaluation of Pawpaw (Carica papaya) seed for controlling reproduction in the Nile Tilapia (Oreochromis niloticus).	61%	Mixed
451	Journal of the Science of Agriculture, Food Technology, and Environment (JSAFE) , 12 (1), 1–8.	76%	AI
452	H., Yesaki, T.	50%	Mixed
453	Y., Donaldson, E.	50%	Mixed
454	M., Du, S.	50%	Mixed
455	J., and Hew, C.	50%	Mixed
456	Growth Performance of Coho Salmon Transgenic for an Exogenous Growth Hormone Gene After Oral Administration of A DNA Vaccine .	60%	Mixed
457	Aquaculture , 194 (1-2), 107–121. https://doi.org/10.1016/S0044-8486(00)00509-0 .	82%	AI
458	Dey, S., Sahoo, L., and Sahoo, P.	79%	AI
459	DNA repair genes play a variety of roles in the development of fish embryos.	70%	Mixed
460	Frontiers in Cell and Developmental Biology, 11, 1123456. https://doi.org/10.3389/fcell.2023.1123456	76%	AI
461	Dinesh, K.R., Lim, T.M., Chua, K.L., Chan, W.K., and Phang, V.P.E.	83%	AI
462	RAPD Analysis: an Efficient Method of DNA Fingerprinting in Fishes.	55%	Mixed
463	Aquaculture Research , 10 (5), 849–854.	61%	Mixed
464	Y., Nwafili, S.	50%	Mixed
465	A. , Haruna, A. and Omorodion , N.G.	65%	Mixed
466	The effect of graded levels of ram testes on sex, growth, and Survival of Oreochromis niloticus (Linnaeus, 1856).	64%	Mixed
467	Nigerian Journal of Fisheries , 13 (1and2), 1085–1092.	53%	Mixed
468	B., Akinwande, A.	50%	Mixed
469	A., and Aliyu, M.	50%	Mixed
470	Anesthetic Effects of Clove (Eugenia aromaticum) Seed Extract on Clarias gariepinus (Burchell, 1822) Fingerlings Under Semi-Arid Conditions.	59%	Mixed
471	Journal of Agricultural Sciences, Belgrade 62 (4) 411-421. https://doi.org/ 10.2298/jas1704411d	73%	AI
472	Diyaware, M.Y., Suleiman, S.B., Aliyu, M., Mohammed, Z.B., Biola, A.A., Popoola, M.O., and Haruna, M.Y.	82%	AI
473	Growth response and some spawning indices of Nile Tilapia (Oreochromis niloticus, Linnaeus 1758) containing piscine DNA.	58%	Mixed
474	The Journal of Basic and Applied Zoology (20125), 86:105 https://doi.org/10.1186/s41936-025-00525-7	72%	AI
475	Du, J., Zhu, T., Tian, T., Song, H., Lei, C., J.	84%	AI
476	Tian, J., Han, L., and Li, S.	81%	AI
477	Genetic diversity analysis and DNA fingerprinting of different populations of largemouth bass (Micropterus salmoides) in China with fluorescence-labeled microsatellite markers.	76%	AI
478	BMC Genomics 26:531	50%	Mixed
479	Dunham, R.A., Chatakondi, N., Nichols, A.J., Kucuktas, H., Chen, T.T., Powers, D.A., Weete, J.D., Cummins, K., and Lovell, R.T.	82%	AI
480	Effect of Rainbow Trout Growth Hormone Complementary DNA on Body Shape, Carcass Yield, and Carcass Composition of F1 and F 2 Transgenic Common Carp (Cyprinus carpio).	65%	Mixed
481	Aquaculture and Fisheries Biotechnology: Genetic Approaches (2nd ed.).	76%	AI
482	Wallingford, Oxfordshire, UK; Cambridge, MA: CABI.	77%	AI
483	Biotechnology 4: 604-611.	50%	Mixed
484	El-Fiky, S.A. and Mehana, E.E.	76%	AI
485	Production of Heat-Tolerant Transgenic Chickens.	75%	AI
486	Genetic and histopathological response.	50%	Mixed
487	Sci ., 18 (1), 123-139.	50%	Mixed
488	Growth Performance, Proximate Muscle Composition and Dress-Out Percentage of Nile Tilapia (Oreochromis niloticus), Blue Tilapia (O . aureus) and their Interspecific Hybrid (♂ O . aureus X ♀ O . niloticus) Cultured in Semi-Intensive Culture System.	74%	AI
489	World's Veterinary Journal , 2 (2), 17-22. http://wvj.science-line.com/	76%	AI
490	Usage of Conventional and Non-Conventional Breeding Methods for the Production of Nile Tilapia in Marine Water.	74%	AI
491	Thesis , Faculty of Agriculture (Saba-Bacha), Alex.	9%	Human
492	University, Alexandria, Egypt.	50%	Mixed
493	The Role of Tilapia Culture in Rural Development .	55%	Mixed
494	In: El-Sayed A-FM, ed.	50%	Mixed
495	Tilapia Culture. 2nd ed.	50%	Mixed
496	Elsevier/Academic Press, 75-295.	50%	Mixed
497	Breeding Studies in Tilapia.	50%	Mixed
498	Thesis , Faculty of Agriculture (Saba-Bacha), Alex.	9%	Human
499	Alteration of the Productive Performance Characteristics of Orechromis niloticus and Tilapia zillii Under the Effect of Foreign DNA Injection.	65%	Mixed
500	Journal of Aquatic Biology and Fisheries , 8 (1),261- 278.	71%	Mixed
501	El-Zaeem, S.Y. and Assem, S.S.	78%	AI
502	Application of Biotechnology in Fish Breeding: I- Production of Highly Immune Genetically Modified Nile tilapia, Oreochromis niloticus , with Accelerated Growth by Direct Injection of Shark DNA into Skeletal Muscles.	68%	Mixed
503	Journal of Aquatic Biology and Fisheries 8 (3),67-92.	75%	AI
504	Y., El-Tawil, N.	50%	Mixed
505	E., and Amer, T.	50%	Mixed
506	Effect of direct injection of shark DNA into skeletal muscles on growth performance, body composition, and feed utilization of Red Tilapia.	64%	Mixed
507	Journal of the Arabian Aquaculture Society , 4 (2), 103–118.	57%	Mixed
508	El-Zaeem, S.Y., Mohammed, M.	50%	Mixed
509	A., Mohammed, E.S., and Hamad, A.E.	80%	AI

#	Sentence	AI Score	Label
510	Production of salinity-tolerant Nile Tilapia, Oreochromis niloticus Through Traditional and Modern Breeding Methods: II.	68%	Mixed
511	Application of Genetically Modified Breeding by Introducing Foreign DNA into Fish Gonads.	58%	Mixed
512	African Journal of Biotechnology, 10 (4), 684-695.	74%	AI
513	El-Zaeem, S.Y., Amer, T.N., and El-Tawil, N.E.	80%	AI
514	Evaluation of the Productive Performance Characteristics of Red Tilapia (Oreochromis sp .) Injected Shark DNA into Skeletal Muscles and Maintained Diets Containing Different Levels of Probiotics and Amino Yeast.	73%	AI
515	African Journal of Biotechnology , 9 (12), 476-487.	69%	Mixed
516	El-Zaeem, S.Y., El-Tawil, N.E. and Amer, T.N.	80%	AI
517	Effect of Direct Injection of Shark DNA into Skeletal Muscles on the Productive Performance Characteristics of Red Tilapia (Oreochromis sp .) Fed at Different Dietary Regimes.	64%	Mixed
518	African Journal of Agricultural Research , 7 (16), 2456-2462.	77%	AI
519	Aquaculture in Africa: Status, Challenges, and Outlook.	73%	AI
520	FAO Fisheries and Aquaculture Circular , 11-15.	63%	Mixed
521	Extraordinary mullet growth through direct injection of foreign DNA.	27%	Human
522	African Journal of Biotechnology , 11 (33), 8295-8301.	75%	AI
523	El- Z aeem, S.Y., Zidan, E.M., El-Dahhar, A.A. and El-saidi, N.	76%	AI
524	Effect of Introducing Foreign DNA into Nile Tilapia, Oreochromis niloticus Gonads on Male Fertility of the Progeny Produced Under Salinity Stress .	58%	Mixed
525	Journal of Veterinary Science and Research , 6(2), 00021.	67%	Mixed
526	Y., El-Tawil, N.E. and Amer, T.	78%	AI
527	Effect of Direct Injection of Shark DNA into Skeletal Muscles on the Productive Performance Characteristics of Red Tilapia (Oreochromis sp.) Fed at Different Dietary Regimes.	64%	Mixed
528	African Journal of Fisheries Science, 11 (2), 001-007. www.internationalscholarsjournals.org.	74%	AI
529	Manipulation of Biotechnology for the Production of Genetically Modified Nile Tilapia (Oreochromis niloticus).	76%	AI
530	Thesis , (Saba-Bacha), Faculty of Agriculture (Saba-Bacha), Alex.	62%	Mixed
531	University, Alexandria, Egypt.	50%	Mixed
532	Global Production – March 2025 Update .	10%	Human
533	Food and Agriculture Organization of the United Nations.	78%	AI
534	Fu, C., Cui, Y., Hung, S.S.O. and Zu, Z.	81%	AI
535	Growth and Feed Utilization by F 4 Human Growth Hormone Transgenic Carp Fed Diet with Different Protein Levels.	46%	Mixed
536	Journal of Fish Biology, 53,115-129.	68%	Mixed
537	Fu , L., Wang, Y., Li, T. and Hu, Y-Q (2021).	77%	AI
538	A Novel Approach Integrating Hierarchical Clustering and Weighted Combination for Association Study of Multiple Phenotypes and a Genetic Variant.	71%	Mixed
539	Genet . 12:654804. doi: 10.3389/fgene. 2021.654804.	78%	AI
540	Garver , K.	50%	Mixed
541	A., Conway , C.	50%	Mixed
542	M., Elliott , D.G., and Kurath , G.	70%	Mixed
543	Analysis of DNA-vaccinated fish reveals viral antigen in muscle, kidney, and thymus, and transient histopathologic Mar .	61%	Mixed
544	Biotechnol. , 7 (5), 540-53.	78%	AI
545	DOI: 10.1007/s10126-004-5129z .	50%	Mixed
546	Clustering for Gene Expression Analysis.	68%	Mixed
547	CEUR Workshop Proceedings (CEUR-WS.org) Education and Research in the Information Society, October 13-14, 2022, Plovdiv, Bulgaria . 17-24 .	70%	Mixed
548	Gomez-Chiarri, M., Livingston, S., Muro-Cacho, M., Sanders, S., and Levine, R.P.	77%	AI
549	Introduction of foreign genes into the tissue of living fish by direct injection and particle bombardment.	54%	Mixed
550	Diseases of Aquatic Organisms, 27 (1), 5-12. doi: 10.3354/dao027005 .	78%	AI
551	Greenbaum, G., Templeton, A.	50%	Mixed
552	R., Zarmi, Y., and Bar-David, S.	76%	AI
553	Allelic Richness Following Population Founding Events—A Stochastic Modeling Framework Incorporating Gene Flow and Genetic Drift.	43%	Mixed
554	PLOS ONE , 9 (12), e115203. https://doi.org/10.1371/journal.pone.0115203 .	81%	AI
555	Past, present, and prospects on microinjection gene transfer in aquaculture .	66%	Mixed
556	IOP Conference Series: Earth and Environmental Science , 1137 (1), 012040. doi:10.1088/1755-1315/1137/1/012040 (doi.org in Bing).	74%	AI
557	Guo, W., Lele, Fu., Wu, Y., Liu, H., Yang, Y., Hu., W., and Xie, S.	80%	AI
558	Effects of dietary protein levels on growth and feed utilization in non-transgenic and growth-hormone-gene transgenic common carp (Cyprinus carpio L.).	73%	AI
559	Aquaculture Reports , 21, 00854 p.10 .	44%	Mixed
560	Hansen, E., Fernandes, K., Goldspink, G., Butterworth, P., Umeda, P.K., and Chang, K.C.	81%	AI
561	Strong Expression of Foreign Genes Following Direct Injection into Fish Muscle.	34%	Human
562	FEBS Letters , 290, 73–76.	10%	Human
563	Haruna, M.A., Salisu, I.B., and Zannah, U.B.	78%	AI
564	Genetic Improvement of African catfish (Clarias gariepinus) using Nile perch (Lates niloticus) Deoxyribonucleic Acid (DNA) .	63%	Mixed
565	Agriculture, Food and Natural Resources Journal, 4 (1), 108-115.	77%	AI
566	Hemeida, A.A., Riad, S.A., and El-Zaeem, S.Y.	80%	AI
567	Genetic Alteration Following the Production of Genetically Modified Nile Tilapia (Oreochromis niloticus).	69%	Mixed
568	Cytol ., 33: 369-387.	50%	Mixed
569	Heppell, J., Davis, H.L.	50%	Mixed
570	Intramuscular Injection of DNA Vaccines in Fish .	67%	Mixed
571	In: Lowrie, D.B., Whalen, R.G.	82%	AI
572	(eds) DNA Vaccines.	50%	Mixed
573	Methods in Molecular Medicine™, vol 29.	34%	Human
574	Humana Press. https://doi.org/10.1385/1-59259-688-6:99	50%	Mixed
575	D., Goldstein, J.	50%	Mixed
576	L., and Brown, M.	50%	Mixed
577	SREBPs: Activators of the complete program of cholesterol and fatty acid synthesis in the liver.	63%	Mixed
578	Journal of Clinical Investigation , 109(9), 1125–1131. https://doi.org/10.1172/JCI15593 .	77%	AI
579	Ikpeme, E.V., Udensi, O.U., Ekaluo, U.B., Kofrreh, M.E., Okolo, C.M., Ekpo, P.B.. and Ogbonna, N.C.	79%	AI
580	Unveiling the Genetic Diversity in Clarias gariepinus using RAPD Fingerprinting Technique.	11%	Human
581	Asian Journal of Animal Sciences , 9 (3), 187–197.	64%	Mixed
582	Jannatun, F., Rahman, M., Karim, S., and Ali, H.	80%	AI
583	Proximate analysis of fish: Nutritional profiling and quality indicators for human consumption.	61%	Mixed
584	Journal of Aquatic Food Product Technology, 32 (4), 215–225.	51%	Mixed
585	Job, B.E., Antai, E.E., Inyang-Etoh, A.P., Otogo, G.A., and Ezekiel, H.S.	79%	AI
586	Proximate Composition and Mineral Contents of Cultured and Wild Tilapia (Oreochromis niloticus) (Pisces: Cichlidae) (Linnaeus, 1758).	75%	AI
587	Pakistan Journal of Nutrition, 14, 195-200. https://doi.org/ 10.3923/pjn.2015.195.200 .	78%	AI
588	Karaket, T., Reungkhajorn, A., and Ponza, P.	67%	Mixed
589	The Optimum Dose and Period of 17α-methyltestosterone Immersion on Masculinization of Red Tilapia (Oreochrom spp .).	50%	Mixed
590	Aquaculture and Fisheries 8:174–179. https://doi.org/10.1016/j.aaf.2021.09.001 .	77%	AI
591	P., Wang, J., & Wang, H.	84%	AI
592	Epigenetic regulation of muscle growth and water holding capacity in fish: Role of DNA methylation and microRNAs .	75%	AI
593	Aquaculture Reports , 18, 100445.	11%	Human
594	P., Gerrits, W.J.J., Gussekloo, S.W.	80%	AI
595	S., and Schrama, J.	50%	Mixed
596	Balancing Protein and Energy in Nile Tilapia Feeds: A Meta-analysis.	62%	Mixed

#	Sentence	AI Score	Label
597	Aquac ., 14,1757–1778. https://doi.org/10.1111/raq.12671 .	50%	Mixed
598	Konstantinidis, I., Sætrom, P., Mjelle, R., Nedoluzhko, A.	76%	AI
599	V., Robledo, D., & Fernandes, J.	82%	AI
600	Major gene expression changes and epigenetic remodelling in Nile tilapia muscle after one generation of domestication.	68%	Mixed
601	Epigenetics, 15 (10), 1052–1067.	68%	Mixed
602	Kumara, A.M.C.P., Jayasooriya, A.P., Satharasinghe, D.	82%	AI
603	A., and Pathirana, E.	50%	Mixed
604	Nutritional Analyses of Black Tiger Prawn (Monodon penaeus) and Nile tilapia (Oreochromis niloticus) from Sri Lanka.	67%	Mixed
605	Research Square , 1-10.	50%	Mixed
606	Kusa, T., Diyaware, M.	50%	Mixed
607	Y., Suleiman, S.	50%	Mixed
608	B., Aliyu, M., Mohammed, Z.	76%	AI
609	B., Ajibike, A.	50%	Mixed
610	B., Popoola, O.	50%	Mixed
611	M., and Haruna, M.	50%	Mixed
612	Growth response and some spawning indices of Nile Tilapia (Oreochromis niloticus , Linnaeus 1758) containing piscine DNA.	52%	Mixed
613	The Journal of Basic and Applied Zoology , 87 (1). https://doi.org/10.1186/s41936-026-00547-9	75%	AI
614	Comparative Study on the Efficiency Of Feed Conversion In Nile Tilapia (Oreochromis Niloticus) Fed with Different Feed Types.	55%	Mixed
615	International Journal of Agriculture and Plant Science , 6 (2), 22-24. www.agriculturejournal.in.	76%	AI
616	U., Alkali, M.	50%	Mixed
617	I., Ibrahim, H.	50%	Mixed
618	H., & Abacha, I.	50%	Mixed
619	Spatio-Temporal Variation of Rainfall, Temperature, and Vegetation in Maiduguri and Environs.	71%	Mixed
620	International Journal of Research and Innovation in Social Science, 9 (12), 3887–3893.	67%	Mixed
621	Lee, P.Y., Costumbrado, J., Hsu, C.Y., & Kim, Y.H.	82%	AI
622	Agarose Gel Electrophoresis for the Separation of DNA Fragments .	61%	Mixed
623	Journal of Visualized Experiments.	50%	Mixed
624	Lee, L., HYPERLINK "https://www.sciencedirect.com/author/7202876938/cho-fat-hui" Hui, C ., HYPERLINK "https://www.sciencedirect.com/author/20334522000/chinmou-juang" Chuang, C ., and Chen, J.	80%	AI
625	Electrotransfer of the epinecidin-1 gene into skeletal muscle enhances the antibacterial and immunomodulatory functions of a marine fish, grouper (Epinephelus coioides), Fish & Shellfish Immunology , 35 (5), 1359-1368. http://dx.doi.org/10.1016/ j.fsi.2013.07.050 .	77%	AI
626	The fresh and brackish water fishes of Lower Guinea, West-Central Africa.	42%	Mixed
627	Latidae. p. 404-406.	50%	Mixed
628	Teugels and C.D.	50%	Mixed
629	Hopkins (eds.) Volume II.	50%	Mixed
630	Collection Faune et Flore tropicales 42.	10%	Human
631	Institut de Recherche pour le Développement, Paris, France, Muséum National d'Histoire Naturelle, Paris, France, and Musée Royal de l'Afrique Centrale, Tervuren, Belgium. 603 pp.	75%	AI
632	Li, J., Liu, Y., Zhang, H., Wang, Q., & Chen, X.	85%	AI
633	Transient expression of foreign DNA in fish cells: Mechanisms and applications.	57%	Mixed
634	Aquaculture International, 27 (3), 567–579. https://doi.org/10.1007/s10499-018-0329-7 (doi.org in Bing	77%	AI
635	Production of Highly Immune Transgenic Chickens by Injection of Quail Bursal DNA.	67%	Mixed
636	Sci ., 12, 81-98.	50%	Mixed
637	Martinez, R., Juncal, J., Zaldivar, C., Arenal, A., Guillen, I., Morera, V., Carrillo, O., Estrada, M., Morales, A., and Estrada, M.	84%	AI
638	Growth Efficiency in Transgenic Tilapia (Oreochromis sp.) Carrying a Single Copy of a Homologous cDNA Growth Hormone.	66%	Mixed
639	Biochemical and Biophysical Research Communications , 267 (1), 466–472.	70%	Mixed
640	B., Aliyu, M., Raji, A.O., and Diyaware, M.Y.	78%	AI
641	Evaluation of Camel Testes for Masculinisation of the Nile Tilapia (Oreochromis niloticus , Linnaeus, 1758).	67%	Mixed
642	Nigerian Journal of Fisheries and Aquaculture 12 (2), 70 – 85. http://www.nijfaq.com.ng .	75%	AI
643	T., Carman, O., Alimuddin, A., Zairin, M.	79%	AI
644	J.R., and Suprayudi, M.	50%	Mixed
645	Growth Performance, Survival Rate, Flesh, and Proximate Composition of Sex-grouped Triploid and Diploid Nile Tilapia (Oreochromis niloticus).	61%	Mixed
646	Sci. , 44 : 290-298. doi:10.3906/vet-1905-79.	72%	AI
647	Analysis of gene diversity in subdivided populations.	66%	Mixed
648	Proceedings of the	50%	Mixed
649	National Academy of Sciences , 70 (12), 3321–3323. https://doi.org/10.1073/pnas.70.12.3321 .	79%	AI
650	E. and Awodiran, M.	50%	Mixed
651	Molecular Characterization of Lates niloticus (Perciformes, Latidae) Populations from Three Nigerian Waterbodies Using Random Amplified Polymorphic DNA and Microsatellite Markers.	68%	Mixed
652	Vestnik zoologii , 51 (1), 31–36. https://doi.org/10.1515/vzoo-2017-0005 .	76%	AI
653	Olopade, O.A., Taiwo, I.O., Lamidi, A.	78%	AI
654	A. and Awonaike, O.A.	50%	Mixed
655	Proximate Composition of Nile Tilapia, Oreochromis niloticus (Linnaeus, 1758) and Tilapia Hybrid (Red Tilapia) from Oyan Lake, Nigeria.	70%	Mixed
656	Bulletin UASVM Food Science and Technology 73 (1), 1-5. https://doi.org/10.15835/buasvmcn-fst:11973 .	71%	Mixed
657	S., Goland, M., and Levavi-Sivan, B.	66%	Mixed
658	Preliminary Report on the Production of transgenic Oreochromis niloticus using Tol2 kit.	65%	Mixed
659	Nigerian Journal of Biotechnology , 27, 34–39.	57%	Mixed
660	Otene, B.B., Iorchor, S.	50%	Mixed
661	I., and Amadi, G.	50%	Mixed
662	Spatio-Temporal Assessment of Proximate Composition of Tilapia (Oreochromis niloticus) and Silver Catfish (Chrysichthys nigrodigitatus), Tombia Segment, New Calabar River, Port Harcourt, Nigeria.	63%	Mixed
663	International Journal of Innovative Food, Nutrition and Sustainable Agriculture , 12 (3), 28-34.	78%	AI
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782	bp Base pair	50%	Mixed
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