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RESEARCH PAPER

# Differential Expression of Insulin-like Growth Factor-1 Gene in Giant Gourami (*Osphronemus goramy*) Fed with Giant Taro Leaves and Commercial Diets: Responses to Glucose and Insulin Challenges

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## Abstract

Understanding how feeding regimes regulate *igf-1 is* crucial for improving growth and carbohydrate use in giant gourami. This study evaluated *igf-1* expression across several tissues its response to different diets and glucose tolerance tests. Juvenile fish (51.99±7.4 g) were fed commercial feed or giant taro leaves (*Alocasia macrorrhizos*) for 8 weeks in controlled aquaria (60×40×40 cm, 10 fish/tank). Growth performance was higher with commercial feed, showing greater specific growth rate (1.77 vs. 0.67 %/day). After 48 h fasting, liver, intestine, pancreas, muscle, brain, spleen, and heart samples were collected. The glucose tolerance test consisted by four injection treatments: saline, glucose (1 g $kg^{-1}$ body weight), double saline, and insulin+glucose (2 IU 100 $g^{-1}$ body weight and 1 g $kg^{-1}$ glucose). Liver *igf-1* expression was quantified at 0, 6, and 18 h post-injection using qPCR. The liver *igf-1* peaked among tissues but declined within 6 h after glucose or insulin+glucose injection ($P<0.05$). Feeding regime affected *igf-1* only in the liver, with different feeds enhancing its response in the glucose tolerance test. These findings indicate hepatic *igf-1* regulates carbohydrate metabolism in giant gourami through glucose utilization and insulin responsiveness.

## Introduction

Carbohydrates are a major source of dietary energy in aquafeeds due to their low cost and wide availability (Zhang et al., 2022). However, many fish species, particularly carnivorous ones, exhibit limited capacity to utilize carbohydrates efficiently, often leading to prolonged hyperglycemia and metabolic imbalance when given high-carbohydrate diets (Kamalam et al., 2017; Polakof et al., 2012). In contrast, herbivorous and omnivorous species such as giant gourami (*Osphronemus goramy*) demonstrate a higher tolerance to carbohydrate-rich feeds, making them promising models for investigating carbohydrate metabolism in aquaculture species (Sari et al., 2022; Thongchaitriwat et al., 2024).

Giant gourami (*Osphronemus goramy*) is one of the freshwater aquaculture species in Southeast Asia and one of the leading aquaculture commodities in Indonesia (Slembrouck et al., 2019). As an omnivorous fish, giant gourami exhibits a greater capacity to utilize carbohydrates compared to carnivorous species. In aquaculture practices, giant gourami is frequently provided with natural feed in the form of giant taro (*Alocasia macrorrhizos*) leaves. The supplementation of fresh giant taro leaves is commonly practiced even when commercial feeds are used in giant gourami farming. Previous studies have demonstrated that the inclusion

of *sente* leaves, either in fresh form or as extracts, can enhance survival and reproductive performance in gourami (Sulhi et al., 2012).

The glucose tolerance test (GTT) is a reliable method for assessing the carbohydrate utilization ability of an organism (Enes et al., 2012; Liu et al., 2018). GTT can be conducted by administering glucose at specific doses, either orally or via injection. This method allows for rapid evaluation of metabolic responses to carbohydrate treatments and to evaluate metabolic flexibility and endocrine responsiveness. In fish, GTT is particularly important because many species exhibit limited ability to regulate postprandial blood glucose (Enes et al., 2009; Polakof et al., 2012). Measuring the rate at which glucose returns to baseline reveals the efficiency of glucose clearance and the capacity of hormones such as insulin and IGF-1 to modulate carbohydrate metabolism (Furuichi & Yone, 1981; Liu et al., 2018). Thus, GTT serves as a practical tool for linking dietary treatments to physiological glucose-handling capacity.

Insulin-like growth factor-1 (IGF-1) is a hormone structurally like insulin. It is synthesized primarily in the liver following the binding of growth hormone (GH) to its receptors in various organs. IGF-1 plays an essential role in regulating protein, lipid, carbohydrate, and mineral metabolism at the cellular level. It is also involved in osmoregulation, cell differentiation and proliferation, and somatic growth. While the liver is the major site of IGF-1 production, it is also synthesized in the brain, muscle, kidney, and intestine (Moriyama et al., 2000). The igf-1 gene has been identified in several fish species, including Chilean flounder (*Paralichthys adspersus*) (Escobar et al., 2011), and golden pompano (*Trachinotus ovatus*) (Ndandala et al., 2024). *Igf*-1 expression is sensitive to both nutrient composition and hormonal cues, including insulin and glucose levels, reflecting the organism's anabolic status. Notably, carbohydrate-rich diets can modulate IGF-1 expression, although the direction and magnitude of response vary depending on species and metabolic capacity (Cleveland et al., 2009).

The igf-1 gene has also been identified in giant gourami (Irmawati et al., 2016). However, its expression has not yet been investigated following dietary and glucose tolerance treatments. To better understand the molecular responses associated with dietary carbohydrate utilization in *O. goramy*, this study investigates the expression of igf-1 gene in the liver and other tissue of fish fed with giant taro (*A. macrorrhizos*) leaves and a commercial pellet diet. Following the feeding trial, fish were subjected to glucose and insulin-glucose tolerance tests. Parameters observed include growth performance and hepatic gene expression, providing insights into the metabolic adaptation of *O. goramy* to different dietary carbohydrate sources and their implications for sustainable aquaculture nutrition.

## Materials and Methods

### Experimental Diets

The treatments in this study consisted of two dietary groups: commercial feed (treatment 1) and giant taro leaves (*Alocasia macrorrhizos*) (treatment 2), each with five replicates. The giant taro leaves used were harvested from Bogor Regency, West Java, Indonesia. Only the leaf blades were used for feeding, while the petioles and midribs were removed. The selected giant taro leaves had petiole lengths ranging from 60 to 80 cm. Giant taro leaves are known to contain a variety of phytochemicals, such as alkaloids, anthocyanins, flavonoids, and cyanogenic glycosides (Arbain et al., 2022). In addition, giant taro is also a source of vitamins A, B, and C (Badadhe et al., 2023).

### Feeding Trial

Giant gourami (*O. goramy*) specimens were obtained from a local fish farmer in Bogor Regency, West Java, Indonesia. The average body weight of the fish used was 51.99±7.4 g. The acclimation process was conducted in aquaria measuring 60 cm×40 cm×40 cm, with a water height of 20 cm and a stocking density of 10 fish per aquarium. During acclimation, fish were fed with commercial feed (nitrogen-free extract [NFE] 46.91%) in the morning and afternoon, and giant taro leaves (NFE 39.63%) in the evening. All feed was provided *at satiation*.

During the feeding trial, experimental diets were administered three times daily until satiety. The proximate composition of the diets is presented in Table 1. The feeding trial was conducted over an eight-week period, with weekly sampling intervals. Water quality management included 50% water exchange every two days and temperature control using a thermostat maintained at 28–30°C. At the end of the trial, production performance metrics were determined by weighing the fish individually and counting the number of fish alive at the beginning and end of the study. The growth performance was calculated based on the methods described by (Huisman & Richter, 1987; Lugert et al., 2014).

**Table 1.** Proximate composition of the experimental diet (dry weight)

| Proximate composition | Commercial feed (%) | Giant taro leaves (%) |
|---|---|---|
| Protein | 31,86 | 25,56 |
| Lipid | 5,31 | 7,95 |
| Crude fiber | 4,05 | 14,58 |
| Ash | 11,87 | 12,28 |
| Nitrogen-free Extract | 46,91 | 39,63 |

**Glucose Tolerance Test**

The glucose tolerance test (GTT) and insulin-glucose tolerance test (IGTT) were conducted on the final day of the 8-week rearing period. GTT test is conducted based on (Furuichi & Yone, 1981), with modifications according to (Handayani 2006). Prior to the test, the fish were fasted for 48 hours. Fish from the same dietary treatment were pooled into a single container and then randomly divided into four experimental groups for the GTT and IGTT. The group test included two control groups and two treatment groups: a single intraperitoneal injection of 0.1 mL of 0.9% NaCl solution (Control 1), glucose injection at 1 g $kg^{-1}$ body weight (Glu), double injection of 0.1 mL of 0.9% NaCl solution (Control 2), and insulin injection at 2 IU 100 $g^{-1}$ body weight followed by glucose injection at 1 g $kg^{-1}$ body weight (Insulin+Glucose). Glucose was administered via intraperitoneal injection, while insulin was administered intramuscularly 5 minutes before glucose injection, following the protocol of Handayani (2006). Each group was divided into 4 aquaria (n= 3 fish per aquaria) according to the scheduled sampling times to reduce handling stress (Figure 1).

**Sample Collection**

The distribution of igf-1 gene expressions in various organs was assessed by collecting the liver, intestine, pancreas, spleen, heart, brain, and muscle tissues. Prior to dissection, fish were anesthetized using 0.5 mL L-1 tranquilizer (Super Stabilizer, Taiwan) at a dose of 0.5 mL $L^{-1}$. Tissue samples were placed in separate microtubes containing 200 µL of GENEzol™ Reagent (Geneaid, Taiwan) per sample and immediately stored at –80°C until total RNA extraction.

For the GTT and IGTT, liver tissue was collected at three time points: before injection (0 h) and after injection (6 h and 18 h) (n= 3 per time point). Each sample was preserved in a separate microtube containing 200 µL of GENEzol™ Reagent and stored at –80°C until RNA extraction.

**Igf-1 Gene Expression Analysis**

Total RNA was extracted using GENEzol™ Reagent (Geneaid, Taiwan). The RNA quality was verified via 1% agarose gel electrophoresis and spectrophotometric analysis of OD260/OD280 using a GeneQuant RNA/DNA Calculator (Pharmacia Biotech, UK). cDNA was synthesized from 50 ng $\mu L^{-1}$ of total RNA using the ReverTraAce® qPCR RT Master Mix with gDNA Remover (Toyobo, Japan).

Quantitative analysis of igf-1 gene expression was performed using real-time polymerase chain reaction (qPCR) on a RotorGene 6000 machine (Corbett, USA) with SensiFAST SYBR® NO-ROX reagent (Bioline, UK). Primers were designed based on the igf-1 gene sequence reported by Irmawati et al. (2016), and β-actin was used as the housekeeping gene (Nasrullah et al., 2019) (Table 2). Each qPCR reaction was performed in a final volume of 20 µL. Primer specificity was confirmed through melting curve analysis at 72–95°C.

The gene expression levels were normalized against β-actin gene expression. Organ-specific igf-1 expression levels under each treatment were expressed relative to that of the brain. Post-injection genes expression in each treatment group was expressed relative to the expression level in the control group and compared with the baseline expression (0 h). Relative gene expression was calculated using the $2^{-\Delta\Delta Ct}$ method (Livak & Schmittgen, 2001).

**Statistical Analysis**

All data were organized using Microsoft Excel 2016 (Microsoft, USA), and statistical analyses were conducted using SPSS version 21 (SPSS Inc., USA). Growth rate data were analyzed using an independent samples t-test at a 95% confidence level. Differences in IGF-1 gene expression among tissues were evaluated using one-way ANOVA, and when significant effects were detected, Duncan's multiple range test was applied ($P<0.05$). Non-homogeneous data were analyzed using the Kruskal-Wallis non-parametric test

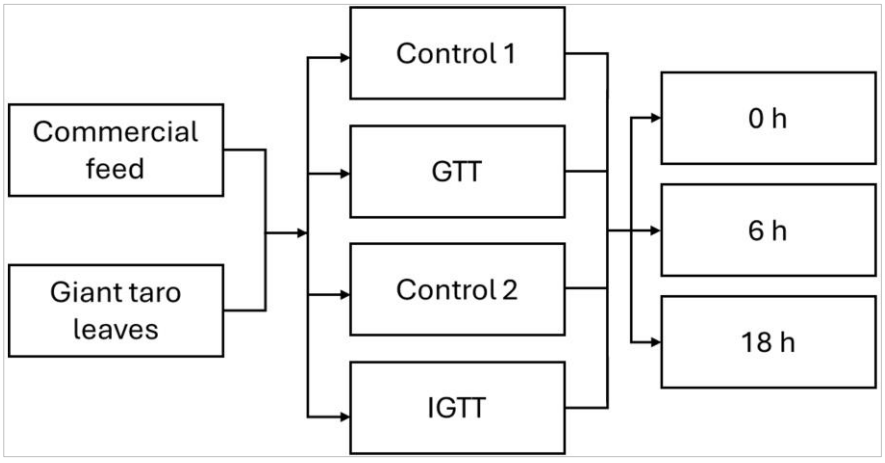


**Figure 1.** Scheme of GTT and IGTT after feeding treatment.

(P<0.05). Comparisons of gene expression within the same organ between treatments, as well as expression following the glucose tolerance test (GTT) and insulin-glucose tolerance test (IGTT), were analyzed using independent samples t-tests with a 95% confidence level. When the assumption of homogeneity of variance was not met, non-parametric analyses were performed, and pairwise comparisons were evaluated using the Mann-Whitney U test (P<0.05).

## Results

### Growth Performance

Giant gourami fed with commercial feed exhibited significantly higher growth performance compared to those fed with giant taro leaves (P<0.05). There was no mortality in both treatments (Table 3).

### Igf-1 Relative Expression

The igf-1 gene was expressed across various organs (Figure 2). Different feeding treatments did not affect the igf-1 gene expression pattern in giant gourami, however, the level expression in giant taro leaves treatment was lower than commercial feed treatment. The highest expression level in both treatments was observed in the liver, while the lowest was detected in the heart. Only expression in liver that significantly differ between treatments (P<0.05).

At each sampling time point, igf-1 gene expression levels between the two feeding treatments were not significantly different (P>0.05). However, when compared to 0 h within each treatment group, igf-1 expression in the commercial feed group showed a significant decrease at 6 h post-GTT (P<0.05) and returning to baseline at 18 h. In contrast, the giant taro leaves group did not exhibit a significant decline in igf-1 expression following the GTT (Figure 3a).

A slightly different expression pattern was observed when fish were pre-injected with insulin. Although different diets did not result in significant differences at the same sampling time, giant gourami fed with giant taro leaves exhibited an earlier and sustained decrease in igf-1 expression, which remained significantly lower up to 18 h (P<0.05). In the commercial feed group, a significant reduction in igf-1 expression was observed only at 6 h post-GTT (Figure 3b).

## Discussion

Giant gourami is one of the prospective aquaculture commodities. This fish is included in the omnivorous fish group that is tolerant to low oxygen, can utilize carbohydrates well, and can even utilize plant leaves well (Arifin et al., 2019, 2020; Setijaningsih et al., 2007). Giant taro leaves are one of the natural foods that are often given to giant gourami. In addition to being a source of energy, giant taro leaves also contain various active ingredients that can maintain the immune system of giant gourami (Sulhi et al., 2012).

In our study, the survival rate did not differ significantly between treatment, but the growth rate and feed efficiency were noticeably lower in the fish fed with giant taro leaves than those receiving the commercial feed. This outcome is expected, as the nutrient composition and digestibility of giant taro leaves are insufficient to meet the energy requirements of giant gourami. The high fiber content and the presence of antinutritional compounds such as oxalates and flavonoids can reduce nutrient digestibility, bind essential minerals, and accelerate gut transit (Badadhe et al., 2023; Thanh et al., 2017), ultimately limiting

**Table 2.** Primers that are used in this study

| Primers | Sequences (5'-3') | Gene | Size (bp) |
|---|---|---|---|
| q-igf-1-R<br>q-igf-1-F | TGT-GTT-GCC-TCG-ACT-TGA-GTT-T<br>GAG-AGC-ACC-TAA-GAG-ACC-TTT-G | *igf-1* | 85 |
| q-act-R<br>q-act-F | GAG-CTG-CGT-GTT-GCC-CCT-GAG<br>ACC-GGA-GTC-CAT-CAC-AAT-ACC-AGT | *β-actin* | 192 |

Note: Primers were synthesized by Integrated DNA Technologies (IDT, USA) with standard desalting purification and 25 nmol synthesis scale.

**Table 3.** Production performance of giant gourami fed with commercial diet and giant taro leaves for 8 weeks

| No | Parameters | Commercial diet | Giant taro leaves |
|---|---|---|---|
| 1 | W0 (g/ind) | 54.97±5.37$^{a}$ | 49.27±7.18$^{a}$ |
| 2 | W56 (g/ind) | 146.77±10.13$^{a}$ | 71.86±1.70$^{b}$ |
| 3 | SR (%) | 100.00±0.00$^{a}$ | 100.00±0.00$^{a}$ |
| 4 | GR (g/day) | 1.64±0.24$^{a}$ | 0.39±0.16$^{b}$ |
| 5 | SGR (%/day) | 1.77±0.27$^{a}$ | 0.67±0.30$^{b}$ |
| 6 | TF (g/ind$^{-}$) | 162.47±17.21$^{a}$ | 111.20±7.72$_{b}$ |
| 7 | FE (%) | 56.46±5.36$^{a}$ | 19.89±8.13$^{b}$ |
| 8 | FCR | 1.78±0.16$^{a}$ | 5.64±2.33$^{b}$ |

Description: W0: Average body weight at day 0, W56: Average body weight at day 56, SR: survival rate, GR: growth rate, SGR: specific growth rate, TF: Total feed, FE: Feed efficiency and FCR: Feed conversion ratio. Superscripts in the same row indicate significant differences between groups (P<0.05).

nutrient absorption and lowering the amount of metabolizable energy available for somatic growth. Additionally, plant-based diets often have reduced palatability, which may decrease feed intake and further impair growth performance. Similar findings have been reported in other herbivorous and omnivorous fish species, where diets containing plant leaves or high levels of structural carbohydrates resulted in depressed growth due to limited digestible energy and imbalances in essential amino acids (Kim et al., 2017; Tran-duy et al., 2008).

Igf-1 is a peptide that plays a role in several biological functions, including growth, reproduction, metabolism, cell proliferation, and cell differentiation (Ndandala et al., 2024). In giant gourami fish, igf-1 is expressed in various organs, including the liver, intestine, pancreas, spleen, muscle, heart, and brain. The highest igf-1 gene expression level was found in the liver, which aligns with the role of igf-1 in metabolic processes. These findings are consistent with those observed in golden pompano (*T. ovatus*) (Ndandala et al., 2024). In general, the igf-1 level expression in giant taro leaves treatment was lower than commercial feed. It might be due to the lower energy intake and lack of nutrient composition in giant taro leaves treatment (Bertucci et al., 2017; Cleveland et al., 2009). Cleveland et al., (2009) reported that feed deprivation led to reduce the plasma concentrations of IGF-1. Furthermore, Qiang et al., (2012) also reported that fish fed with lower protein have lower serum and hepatic igf-1 expression. In the other hand, low energy intake leads to lower growth. Lower growth indicates a lower growth hormone (GH) production, meanwhile GH is the primary regulator for igf-1 synthesis and secretion fish (Triantaphyllopoulos et al., 2020). This result was in line with our study which showed a lower igf-1 expression and growth rate in giant taro leaves treatment.

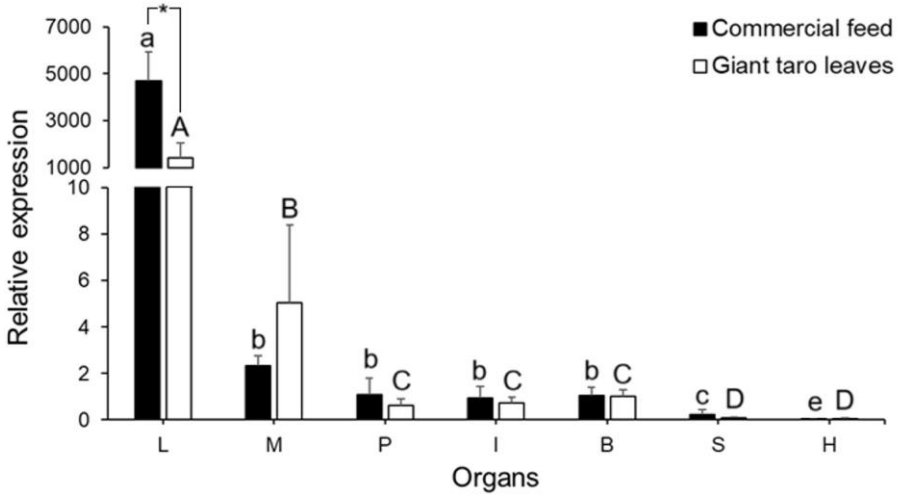


**Figure 2.** Expression distribution of the *igf-1* gene in various organs of giant gourami after being fed with commercial feed and giant taro leaves. Data were relative to brain gene expression and normalized with the β-actin gene. Different letters on each graph indicate significantly different data within the same treatment (P<0.05). Lowercase letters indicate commercial feed treatment and uppercase letters indicate giant taro leaves. Asterisks indicate significant differences between treatments. L: liver, M: muscle, P: pancreas, I: intestine, S: spleen, B: brain, H: heart.

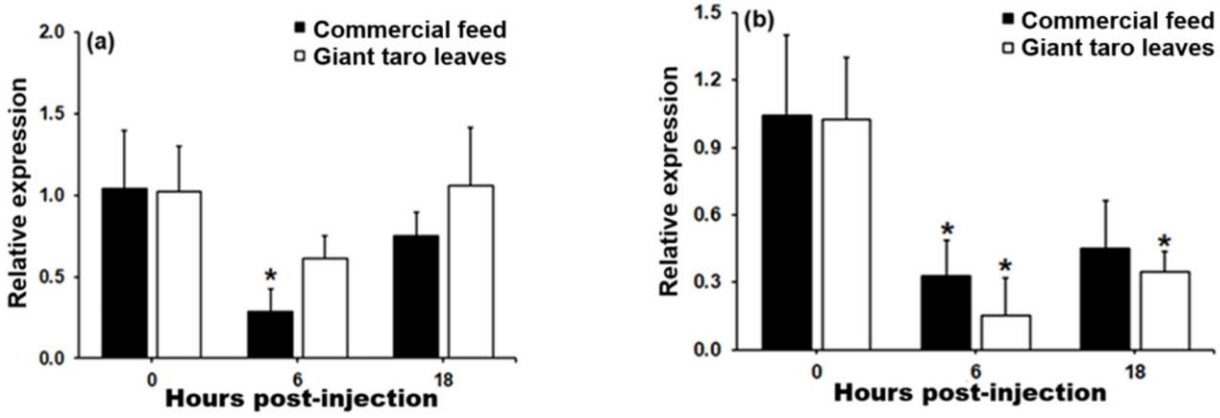


**Figure 3.** Igf-1 gene expression after glucose tolerance test with 1 g $kg^{-1}$ glucose injection (a) and 2 IU 100 $g^{-1}$ insulin+1 g $kg^{-1}$ glucose injection (b) (n=3). The asterisk (*) indicates a significant difference with the 0-hour data (P<0.05).

Glucose tolerance tests (GTTs) are commonly used to evaluate an organism's ability to metabolize carbohydrates (Enes et al., 2012; Liu et al., 2018). This method involves administering glucose either orally or through injection at a specific dosage, enabling researchers to observe the metabolic response to carbohydrate intake over a short period. Differences in nutrient composition and feed digestibility led to significantly different molecular responses in both treatments. These results indicate that different feeding regimens caused changes in the igf-1 gene expression pattern post-GTT. Generally, igf-1 expression decreased after injection with either glucose or insulin-glucose. The commercial feed and giant taro leave groups showed different responses to insulin. Giant gourami treated with commercial feed that was injected with insulin-glucose had relatively similar igf-1 expression levels compared to those injected only with glucose and its expression was only significantly reduced at 6-hour post injection. In contrast, giant gourami fed with giant taro leaves showed a significantly lower igf-1 expression when injected with insulin-glucose. The igf-1 level after insulin-glucose injection in giant taro leaves treatment remains low until 18-hours post injection. IGF-1 has been known to play a role to stimulate glucose uptakes into the cells (Enes et al., 2010). Its expression is tightly regulated by various factors, including nutrient availability, especially carbohydrate and protein, and insulin signaling. Study in nile tilapia showed that administration of feed with 30% of carbohydrate and refeeding after 30 days of fasting in rockfish are leading to an increase in igf-1 level (Bersin et al., 2023; Liu et al., 2018). However, no significant effects on plasma igf-1 were found in European sea bass (*Dicentrarchus labrax*) (Enes et al., 2010).

Glucose injections provide a sudden influx of energy after 24 hours of fasting. Several studies showed that fasting for several hours to several days can reduce igf-1 expression, but it will increase again after refeeding. The postprandial elevation of igf-1 levels varies among fish species (Bersin et al., 2023). The upregulation of igf-1 expression is presumed to result from an increase in blood insulin levels during glucose metabolism. Insulin may enhance igf-1 activity to stimulate the glucose transporter (GLUT) production. This explains the observed increase in igf-1 levels following glucose administration.

However, when Giant gourami was injected with insulin prior to glucose injection, the igf-1 expression occurred at a slower rate, with expression levels not returning to baseline even at 18 hours post-injection. This delay is presumed to be associated with a hyperinsulinemia state and potential metabolic stress resulting from two consecutive injections. Elevated levels of insulin and glucose can activate the PI3K/Akt signaling pathway and inactivate the transcription factor FOXO1, which plays a role in the regulation and activation of the igf-1 gene. Excessive PI3K/Akt activation may lead to a reduction in hepatic GH receptor expression, thereby weakening GH signaling for igf-1 induction (Fuentes et al., 2013). This mechanism is hypothesized to underlie the delayed increase in igf-1 expression following glucose injection. Further studies are required to validate this hypothesis.

## Conclusion

*Igf*-1 is expressed in various organs with the highest expression level in the liver of giant gourami. Different feeds cause differences in the level of *igf*-1 expression in various organs. *Igf*-1 expression showed a significant decrease after insulin injection. Giant gourami fed with giant taro leaves did not show significant changes in gene expression at any sampling time after glucose injection but decreased significantly when injected with insulin and glucose.

## Ethical Statement

The protocol in this study was approved by the Animal Care and Use Committee of IPB University, Indonesia (Grant No. 192-2021 IPB). All surgical procedures were carried out under MS-222 anesthesia, with every effort taken to reduce suffering.

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## Author Contribution

Conceptualization, D.N.S, A.A, M.A.S.; methodology, software, and formal analysis: D.N.S, J.E.; investigation, writing-original draft preparation, D.N.S; writing-review, editing, and validation: J.E., M.A.S, A.A. All authors have read and agreed to the published version of the manuscript.

## Conflict of Interest

The authors state that they have no financial, non-financial, professional, or personal conflicts of interest that might have influenced the research presented in this paper.

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