



# Comparative modeling of growth in rainbow trout (*Oncorhynchus mykiss*) strains with distinct skin pigmentation using the Gompertz function

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## ABSTRACT

This study aimed to evaluate the growth of four strains of rainbow trout, including wild-type, cobalt-blue, yellow-albino, and white-albino. Juveniles  $3.07 \pm 0.11$  g were distributed into four groups per strain in triplicate (12 tanks). Feeding was standardized with a diet containing 45 % crude protein offered ad libitum three times daily. Feed conversion ratio, weight gain, and mean body weight, were performed at 60, 120, 180, and 270 days. The data were fitted to the Gompertz model  $y = Ae^{-Be^{-Kx}}$ , allowing estimation of asymptotic weight, growth rate, inflection point, as well as absolute and relative growth rate. The yellow-albino strain exhibited the highest performance, reaching a final weight of  $301.70 \pm 32.45$  g. Wild-type and cobalt-blue strains showed intermediate performance of  $237.79 \pm 16.06$  g and  $221.92 \pm 20.83$  g, respectively, whereas the white-albino strain presented the lowest weight  $145.80 \pm 23.03$  g on day 270 ( $P < 0.05$ ). Gompertz model showed effective with high adjusted coefficients of determination, confirming the reliability of the fit. Estimates revealed higher asymptotic weight and growth rate for the yellow-albino strain ( $1826.6$  g and  $3.3 \pm 0.9$  g) compared to the wild-type strain ( $895.6$  g and  $1.9 \pm 0.1$  g). The weight at inflection indicated that the white-albino ( $725.8 \pm 140.3$  g) and yellow-albino ( $709.2 \pm 273.8$  g) strains were different ( $P < 0.05$ ) from the wild-type ( $339.3 \pm 38.1$  g) and cobalt-blue ( $309.5 \pm 53.5$  g) strains. The age at inflection indicated the white-albino strain ( $478.6 \pm 53.0$  days) was differed ( $P < 0.05$ ) from the yellow-albino ( $384.6 \pm 55.4$  days), cobalt-blue ( $334.6 \pm 54.2$  days) and wild-type ( $301.2 \pm 12.1$  days) strains. The findings underscore the importance of genetic selection in aquaculture, especially for the yellow-albino strain and emphasize the need to further investigate the metabolic factors that influence the performance of the white-albino strain.

## 1. Introduction

The growing demand for healthy food over the years has led to a gradual increase in the search for diverse dietary options, positioning aquaculture as a significant field of study within this context. The species *Oncorhynchus mykiss* (Walbaum, 1792), commonly known as rainbow trout, is distinguished by its characteristic iridescent skin pigmentation resembling a rainbow. Rainbow trout belong to the family *Salmonidae* and exhibit morphological similarities to brown trout and Atlantic salmon (FAO, 2011). In 2024, global salmonid production reached approximately 950 thousand metric tons for trout and 3.15

million metric tons for Atlantic salmon (FAO, 2024). Although trout production volume remains considerably lower compared to Brazilian aquaculture output estimated at 1.6 tonnes (IBGE, 2024), rainbow trout continue to hold a well-established market niche.

A previous study carried out at the Fisheries Institute, Campos do Jordão, São Paulo State, Brazil, showed that the color inheritance pattern in four phenotypes of rainbow trout is related to differences in their performance and growth (Hattori et al., 2020). Growth or development in animal size can be observed through changes in body structures, such as the muscular, skeletal, and digestive systems (Mansano et al., 2017). Fish change their growth pattern as they approach sexual

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maturity, and this change results from the allocation of nutrients between the somatic growth phase and the onset of reproductive growth (Dumas et al., 2007). The growth rate of rainbow trout is high, reaching a maximum length of 80 cm, but their most common size ranges between 20 and 40 cm, with a weight ranging from 500 g to 6 kg (Salem et al., 2013). However, in Brazil, their commercial weight starts between 250 g, and they are called portion-sized trout (Tabata; Portz, 2004; Woynarovich; Hoitsy; Moth-Poulsen; 2011). The biological growth characteristics of rainbow trout (*Oncorhynchus mykiss*) for weight and length found in free fish were 21.7 kg and 106.68 cm (IGFA, 2018). Other changes in weight and size are related to rearing time, during which such characteristics as growth rates with acceleration and deceleration periods can be defined, varying according to an organism's developmental stages (Grimm et al., 2011; Lourenço and Fowler, 2002).

Nonlinear equations applied to growth curves have demonstrated efficient in defining strategies for genetic improvement, nutrition, and animal management based on their flexibility in using weight-age data, along with appropriate parameters for biological interpretation (Pereira et al., 2014; Dumas, 2010). Modeling using the Gompertz equation is also well accepted for determining growth rates of species through weight-age data. However, the Gompertz function, which models sigmoid-shaped growth over time, also allows for an inflection point assumption, which refers to growth when the organism reaches 37 % of its final asymptotic weight or size (Koya and Goshu, 2013). Application of the Gompertz curve in studies with rainbow trout is supported by studies of both wild species in free-living conditions (Silliman, 1969) and aquaculture (Sloat and Reeves, 2014).

According to Tjørve and Tjørve (2017), Gompertz models are widely employed in growth analysis, and their parameters directly influence the shape of the curve. Therefore, the objective of this study was to evaluate the performance and growth of rainbow trout (*Oncorhynchus mykiss*) strains with distinct skin pigmentation patterns using the Gompertz model

2. Materials and methods

2.1. Location, biological material, and facilities

The experiment was carried out from September 2023 to August 2024 at the Dr. Ascânio Carvalho de Faria Salmoniculture Research Center, Campos do Jordão – Fisheries Institute, São Paulo State, Brazil, which is located at 22° 41' south latitude, 45° 28' west longitude, and 1525 m above sea level. The wild-type female (bbaa) crossed with a white-albino male (resulting from the B+A+ genotype) produces offspring with genotypes that can lead to the four observed phenotypes:

white-albino (B+A+), cobalt-blue (B+aa), yellow-albino (bbA+), and wild-type (bbaa), as shown in Fig. 1. The eggs were placed in drawer incubators until the yolk sac was absorbed after which fry were removed from the incubator and transferred to fry tanks where they began feeding on powdered feed containing 48 % crude protein. Fry remained in the laboratory for approximately 30 days. After this period, they were transferred to masonry tanks measuring 0.50 × 2 m and remained there until the selection of batches for the experiment (60 days).

Screening was performed by separating the four color-pattern strains and discarding undersized or oversized fry, which resulted in 2031 white-albino fry, 1969 yellow-albino fry, 1971 blue fry, and 2306 wild-type fry. These quantities follow the expected inheritance pattern from the cross between heterozygous white trout and wild-type colored trout. Thus, 25 % of the fish exhibited wild coloration (aabb), 25 % white-albino (AaBb), 25 % yellow-albino (aaBb), and 25 % blue (Aabb), as reported by Hattori et al. (2020).

Following screening procedures, 300 mixed-sex juveniles (males and females) were selected for each strain. These were subsequently redistributed into four experimental groups, including wild-type, cobalt-blue, yellow-albino, and white-albino, in triplicate, resulting in a total of 12 tanks. The initial mean weight of the juveniles at the onset of the experiment was 3.07 ± 0.11 g across all four strains. Fish were housed in 2 m³ tanks with a continuous water flow rate of 2000 liters per hour per tank throughout the cultivation period under natural photoperiod conditions. The water temperature was measured daily while the dissolved oxygen was measured with a Hanna oximeter (HI 98193), and the pH was measured weekly using a Hanna device (HI9811–51). The fish were fed a commercial diet containing 45 % crude protein (nutritional composition detailed in Table 1), administered ad libitum three times daily for the entire duration of the trial. Feed particle size was adjusted according to the growth stage of the fish.

As the fish grew, they were weighed using an analytical balance to

Table 1  
Proximate composition of experimental diet administered to rainbow trout.

| Proximate composition            | %     |
|----------------------------------|-------|
| Moisture and volatiles           | 7.43  |
| Crude protein                    | 45.78 |
| Ether extract by acid hydrolysis | 7.94  |
| Ash content                      | 11.51 |
| Carbohydrates (by difference)    | 27.34 |
| Calcium                          | 3.23  |
| Phosphorus                       | 1.82  |
| Gross Energy                     | 4637  |

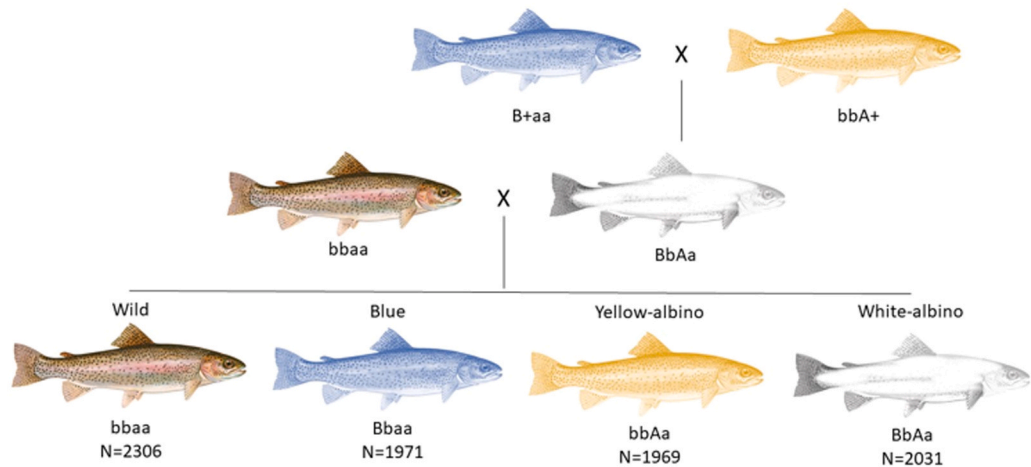


Fig. 1. Schematic representation illustrating the color inheritance pattern of the cross between heterozygous white-albino trout and wild-type skin pigmentation rainbow trout.

determine mean body weight, apparent feed conversion ratio, and weight gain. A sample of 90 fish (30 individuals per tank) was randomly collected at the beginning of the experiment and at 60, 120, 180, and 270 days of cultivation. Following a 24-hour fasting period, fish were anesthetized with 50 mg/L of eugenol (Ecadil brand) diluted in water with an average exposure time of 30 s to perform all procedures during the designated sampling intervals. Afterward, the fish were returned to their respective tanks. All experimental procedures were conducted in accordance with the guidelines of the Animal Ethics Committee and were approved by the Animal Experimentation Ethics Committee of the Fisheries Institute (CEEAIIP), protocol CEUA-IP 003/2022.

The growth study was conducted by fitting all fish weight and age data to the Gompertz model calculated as  $y = Ae^{-Be^{-Kx}}$ , where A represents the asymptotic weight or the mature body size, B is a scaling parameter (integration constant), and K denotes the growth rate relative to maturity or the maturation index (Tjørve and Tjørve, 2017). In these models, the error associated with each observation follows a normal distribution, as verified by the Shapiro-Wilk test (Draper and Smith, 1998). Model fitting was performed separately for each batch (tank) with three replicates per rainbow trout strain. Curve parameters for each strain were compared using 95 % confidence intervals. The equations and adjusted coefficient of determination ( $R^2_{Adj}$ ) were reported. Estimates were obtained using weighted least squares and autoregressive error structures (Draper and Smith, 1998; Santos et al., 2008), ensuring variance homoscedasticity. A weighting factor was applied as the inverse of weight variance, thereby validating F-tests and confidence intervals.

Absolute growth rate (AGR) and relative growth rate (RGR) were calculated using the expressions  $AGR = K \ln(Ay^{-1})$  and  $RGR = K \ln(Ay^{-1})$ , respectively. Inflection weight and age were calculated as  $WI = Ae^{-1}$  and  $AI = (\ln B) K^{-1}$  (Laird, 1966; Fitzhugh Jr, 1976; Gamito, 1998). Analysis of variance (ANOVA) was performed for these growth metrics with means compared using Tukey's test at a 5 % significance level. Model fitting procedures followed Santos et al. (2008), employing PROC MODEL and PROC GLM routines in SAS for Windows, version 8.01.

### 3. Results

Water quality parameters showed no statistical differences ( $P > 0.05$ ) among strains. The average oxygen levels were maintained at  $(6.84 \pm 0.03)$  mg/L, and the same occurred with the pH with average values of  $(6.4 \pm 0.02)$ . The average temperature was  $(15.6^\circ\text{C} \pm 1.56)$  for the maximum and  $(13.5^\circ\text{C} \pm 1.89)$  for the minimum, both ideal for rainbow trout farming.

At the beginning of the experiment, the juveniles from the four strains exhibited similar mean weights: wild-type ( $3.25 \pm 0.07$  g), cobalt-blue ( $3.04 \pm 0.10$  g), yellow-albino ( $3.07 \pm 0.09$  g), and white-albino ( $2.91 \pm 0.20$  g) with no statistically significant differences ( $P > 0.05$ ). Apparent feed conversion ratio, weight gain, and live weight at 60, 120, and 180 days of cultivation are presented in Table 2.

At 60 days, the white-albino strain showed significantly poorer feed conversion, weight gain, and mean body weight compared to the other strains ( $P < 0.05$ ). During the same period, the wild-type strain exhibited higher live weight and weight gain compared to the cobalt-blue and white-albino strains ( $P < 0.05$ ), while the yellow-albino strain did not differ significantly from the wild-type and cobalt-blue strains ( $P > 0.05$ ). At 120 days, the wild-type strain differed significantly from the white-albino strain ( $P < 0.05$ ). At 180 days, the yellow-albino strain showed a significant difference ( $P < 0.05$ ) compared to the white-albino strain. However, weight gain and mean body weight revealed changes relative to the previous period since the white-albino strain continued to exhibit inferior performance ( $P < 0.05$ ) compared to the wild-type, cobalt-blue, and yellow-albino strains.

At the end of the 270-day cultivation period, the yellow-albino strain exhibited superior performance compared to the other strains

**Table 2**

Harvest weight, weight gain and feed conversion rate in different culture periods of rainbow trout (*Oncorhynchus mykiss*).

| Period   | Strain        | Weight (g)           | Weight gain (g)      | FCR                |
|----------|---------------|----------------------|----------------------|--------------------|
| 60 days  | Wild-type     | 15.95 $\pm$ 0.46 A*  | 12.27 $\pm$ 0.43 A   | 1.70 $\pm$ 0.11 A  |
|          | Cobalt-blue   | 13.56 $\pm$ 0.51 B   | 10.52 $\pm$ 0.18 B   | 1.60 $\pm$ 0.19 A  |
|          | Yellow-albino | 14.68 $\pm$ 0.82 AB  | 11.10 $\pm$ 0.80 AB  | 1.73 $\pm$ 0.11 A  |
|          | White-albino  | 9.68 $\pm$ 0.23 C    | 6.45 $\pm$ 0.30 C    | 2.41 $\pm$ 0.02 B  |
| 120 days | Wild-type     | 54.00 $\pm$ 1.37 A   | 38.09 $\pm$ 1.63 A   | 1.35 $\pm$ 0.40 A  |
|          | Cobalt-blue   | 47.64 $\pm$ 1.53 A   | 34.08 $\pm$ 2.02 A   | 1.54 $\pm$ 0.07 AB |
|          | Yellow-albino | 50.94 $\pm$ 2.71 A   | 36.26 $\pm$ 3.46 A   | 1.38 $\pm$ 0.13 AB |
|          | White-albino  | 33.68 $\pm$ 3.76 B   | 24.00 $\pm$ 3.92 B   | 2.04 $\pm$ 0.37 B  |
| 180 days | Wild-type     | 119.11 $\pm$ 6.64 A  | 65.52 $\pm$ 5.82 A   | 1.54 $\pm$ 0.10 AB |
|          | Cobalt-blue   | 113.72 $\pm$ 11.81 A | 65.31 $\pm$ 10.51 A  | 1.53 $\pm$ 0.05 AB |
|          | Yellow-albino | 123.13 $\pm$ 6.12 A  | 71.99 $\pm$ 3.47 A   | 1.42 $\pm$ 0.04 A  |
|          | White-albino  | 78.07 $\pm$ 12.52 B  | 44.25 $\pm$ 8.64 B   | 1.72 $\pm$ 0.16 B  |
| 270 days | Wild-type     | 237.79 $\pm$ 16.06 B | 113.47 $\pm$ 16.81 B | 1.65 $\pm$ 0.04 A  |
|          | Cobalt-blue   | 221.92 $\pm$ 20.83 B | 103.36 $\pm$ 8.84 CB | 1.45 $\pm$ 0.22 A  |
|          | Yellow-albino | 301.70 $\pm$ 32.45 A | 171.17 $\pm$ 30.09 A | 1.51 $\pm$ 0.21 A  |
|          | White-albino  | 145.80 $\pm$ 23.03 C | 65.19 $\pm$ 9.72 C   | 1.40 $\pm$ 0.17 A  |

Notes: FCR, Feed Conversion Ratio. \*Values followed by different letters in the same column in each period are not equal by Tukey's test at significance 5 %, ( $\alpha = 0.05$ ).

( $P < 0.05$ ). The wild-type and cobalt-blue strains demonstrated intermediate performance, whereas the white-albino strain consistently showed inferior results across all measured parameters throughout the entire cultivation period. Regarding feed conversion ratio, no significant differences were observed among the strains during this final phase ( $P > 0.05$ ).

Table 3. Estimated parameters of the Gompertz model. The estimate of asymptotic weight "A" was higher in the yellow-albino strain when compared to the wild-type. The growth rate "K" relative to maturity was higher for the wild-type (0.0058) compared to either the yellow-albino (0.0048) or white-albino (0.0041). The model fits are presented in Fig. 2. The fitting of weight data for rainbow trout strains was good (high  $R^2$  adjusted), showing applicable estimates and reliability.

According to the Gompertz model, the final estimated weights at day 270 of cultivation of the rainbow trout were 277.70 g, 287.13 g, 320.19 g, and 203.71 g for the wild-type, blue, yellow-albino, and white-albino strains, respectively. The white-albino strain showed lower

**Table 3**

Estimated parameters "A" and "K" and confidence limits by Gompertz growth model from weight-age data of rainbow trout with different skin pigmentation.

| Strain        | Parameters |          | Confidence limits |        |         |         |
|---------------|------------|----------|-------------------|--------|---------|---------|
|               |            |          | A (g)             |        | K (%)   |         |
|               | A (g)      | K (%)    | Lower             | Upper  | Lower   | Upper   |
| Wild-type     | 895.6b*    | 0.0058a  | 760.0             | 1069.7 | 0.00545 | 0.00614 |
| Cobalt-blue   | 1012.0ab   | 0.0055ab | 753.7             | 1394.7 | 0.00497 | 0.00597 |
| Yellow-albino | 1826.6a    | 0.0048bc | 1223.7            | 2789.9 | 0.00429 | 0.00538 |
| White-albino  | 1734.2ab   | 0.0041c  | 939.3             | 3758.9 | 0.00337 | 0.00474 |

\* Notes: Estimates followed by different letters in the same column are not equal by overlapping the confidence intervals at 5 %.

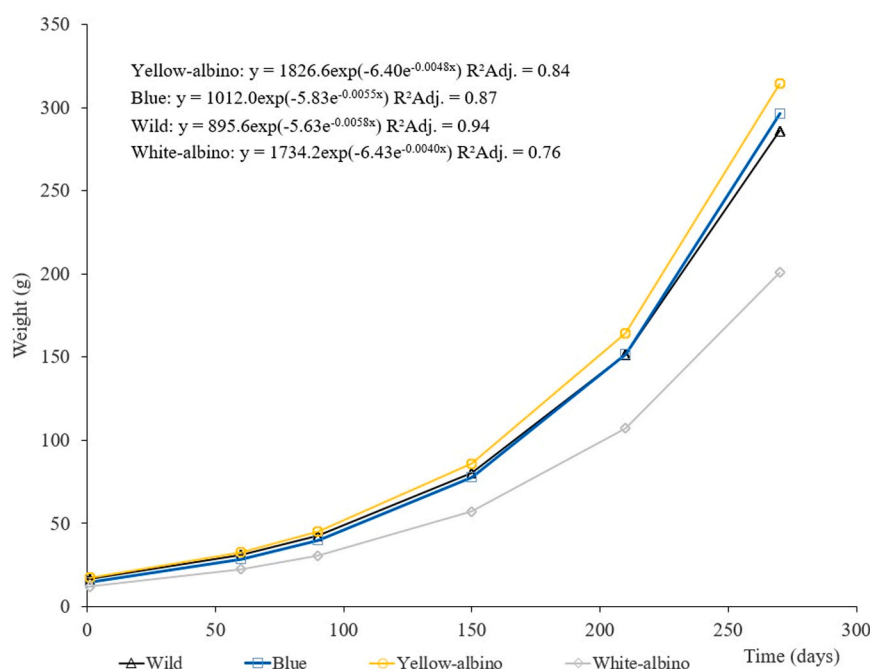


Fig. 2. Gompertz model for rainbow trout (*Oncorhynchus mykiss*) strains. Each point represents the estimated average of thirty fish from each strain.

final weight ( $P < 0.05$ ) when compared to the other strains (Fig. 2).

Table 4 presents the weight, age, AGR and RGR at the inflection point, as well as the absolute growth rates of the white-albino and yellow-albino strains when compared to the wild-type and blue strains ( $P < 0.05$ ). The absolute growth rates (AGR) showed that the age at the inflection point was lower for the wild-type and blue rainbow trout strains compared to that of the white-albino strain ( $P < 0.05$ ). Relative growth rates (RGR), on the other hand, showed the opposite trend in that wild-type and blue strains showed higher RGR when compared to the yellow-albino and white-albino strains. AGR and RGR fit for all data are presented in Figs. 3 and 4.

#### 4. Discussion

Feed conversion efficiency, weight gain, and average weight are essential parameters for evaluating the performance of fish in aquaculture. In this study, four strains of rainbow trout (*Oncorhynchus mykiss*), including wild-type, blue, yellow-albino, and white-albino, were analyzed to identify new color variations that might have commercial value. Therefore, the performance of these strains was observed over a period of 270 days from 3.5 g fingerling until reaching market weight

(about 250 g).

The results indicated that the yellow-albino strain exhibited superior performance, followed by the wild-type and cobalt-blue strains, both of which demonstrated intermediate viability for aquaculture. In contrast, the white-albino strain consistently showed markedly inferior performance compared to that of the other strains. Superiority of the yellow-albino strain may be attributed to genetic and physiological factors that influence feed efficiency and growth, underscoring the importance of selecting strains with high productive potential to optimize yield and maximize economic return in aquaculture systems.

Previous studies suggest that the genotypes responsible for pigmentation in rainbow trout may negatively affect both growth and nonspecific cellular defense mechanisms (Dobosz et al., 2000; Okumuş et al., 2001). The absence of melanin production in the skin, a hallmark of albinism, is associated with disruption of the melanocortin regulatory pathway that adversely impacts feeding behavior, growth, stress response, and immune function (Guillot et al., 2016; Maaser et al., 2006; Pinto et al., 2019). However, field research conducted by Kayhan, Bahrioglu and Özl (2025) revealed that albino rainbow trout exhibited significant advantages over pigmented individuals. In that study, albino specimens demonstrated accelerated growth and greater resistance to infections and environmental fluctuations (Kayhan et al., 2025).

The implications of albinism in rainbow trout remain a subject of ongoing debate since some studies report developmental challenges in albino individuals, while others highlight improved efficiency compared to pigmented or wild-type strains. In the present study, contrasting performance was observed among the albino strains such that the yellow-albino strain achieved the highest growth metrics, whereas the white-albino strain exhibited the lowest performance across all evaluated parameters.

Skin pigmentation is increasingly recognized as a determinant of growth performance in fish (Vissio et al., 2021; Djurdjević et al., 2019). Albinism, characterized by impaired melanin synthesis, is commonly associated with disruptions in the melanocortin regulatory pathway, with documented consequences for feeding behavior, growth, stress responsiveness, and immune function (Guillot et al., 2016; Maaser et al., 2006; Pinto et al., 2019). Nonetheless, contrasting evidence has emerged. Kayhan et al. (2025) demonstrated that albino rainbow trout may outperform pigmented conspecifics, exhibiting accelerated growth

**Table 4**  
Mean and standard deviation of growth parameters of rainbow trout (*Oncorhynchus mykiss*) strains, according to the Gompertz model.

| Strain | WI (g)                   | AI (g)                  | AGR (g/days)          | RGR ( $\times 10^{-3}$ ) % |
|--------|--------------------------|-------------------------|-----------------------|----------------------------|
| Wild   | 339.31 $\pm$ 38.19<br>B* | 301.25 $\pm$ 12.09<br>B | 1.95 $\pm$ 0.16 B     | 5.76 $\pm$ 0.18 A          |
| Blue   | 309.58 $\pm$ 53.51<br>B  | 334.65 $\pm$ 54.25<br>B | 1.77 $\pm$ 0.31 B     | 5.39 $\pm$ 0.54<br>AB      |
| Yellow | 709.21<br>$\pm$ 273.80 A | 384.69 $\pm$ 55.45<br>B | 3.36<br>$\pm$ 0.98 A  | 4.88 $\pm$ 0.54 B          |
| White  | 725.87<br>$\pm$ 140.37 A | 478.63<br>$\pm$ 53.06 A | 2.83 $\pm$ 0.26<br>AB | 3.95 $\pm$ 0.39 C          |

WI, weight at inflection point; AI, age at inflection point; AGR, absolute growth rate; RGR, relative growth rate at inflection point. Means with the same letter in the column are not different by Tukey test at 5 %.

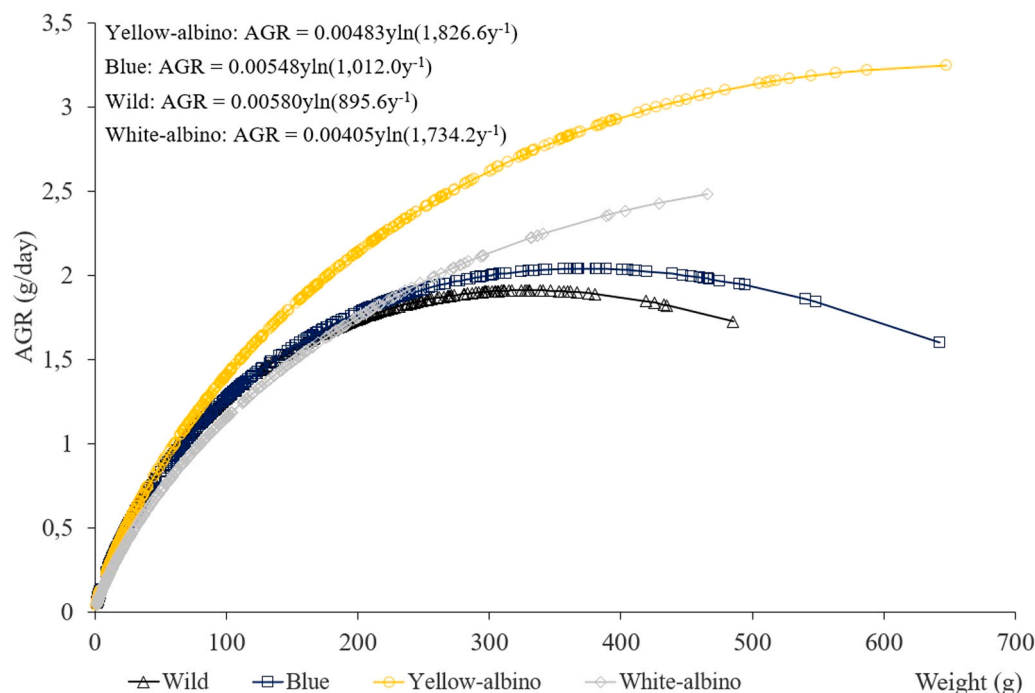


**Fig. 3.** Absolute Growth Rate (AGR) of rainbow trout (*Oncorhynchus mykiss*) strains. Each point represents the estimate of each observation ( $n = 450$  for each strain).

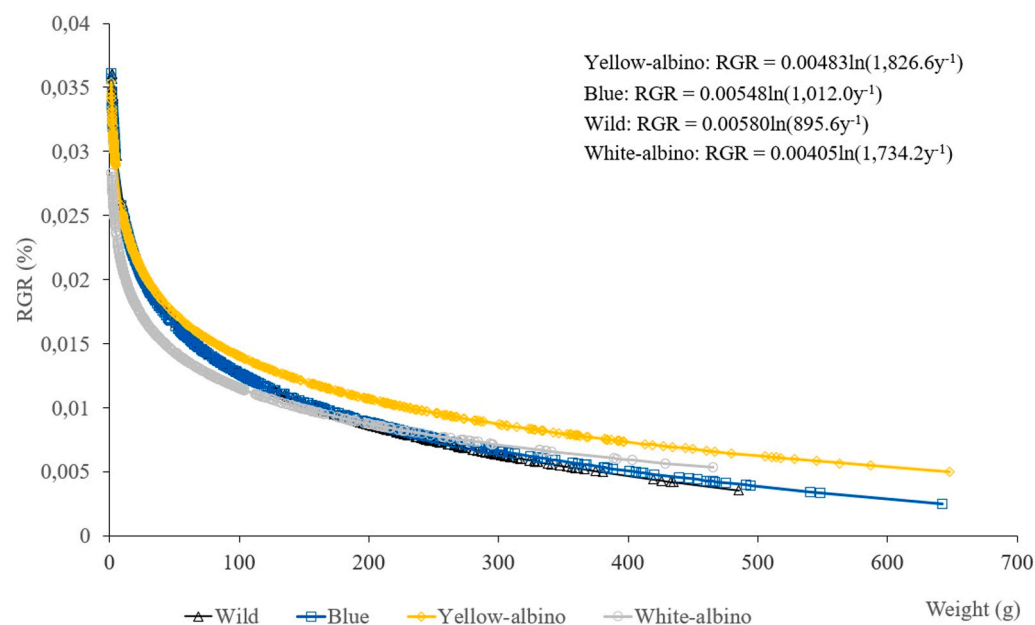


**Fig. 4.** Relative Growth Rate (RGR) of rainbow trout (*Oncorhynchus mykiss*) strains. Each point represents the estimate of each observation ( $n = 450$  for each strain).

and enhanced resilience to pathogenic and environmental stressors. These discrepancies underscore the unresolved and context-dependent nature of albinism-related performance in rainbow trout.

In the present study, marked performance divergence was detected among albino strains. The yellow-albino strain consistently exhibited superior growth, whereas the white-albino strain showed the lowest performance across all evaluated traits. Such divergence likely reflects strain-specific genetic architectures interacting with environmental conditions. External factors, including temperature, diet composition, and light regime, are known modulators of pigmentation-related gene expression and, consequently, of developmental and metabolic outcomes.

Color morphs in rainbow trout, such as yellow-albino and cobalt or metallic blue, were first described in the 1970s and are predominantly associated with recessive inheritance patterns, frequently accompanied by deficits in growth and reproductive capacity (Kincaid, 1975; Nakamura et al., 2001). In this context, the inferior performance of the white-albino strain may be partially attributed to its heterozygous dominant inheritance pattern, which may constrain metabolic flexibility. Conversely, the absence of a dominant allele in the yellow-albino strain may permit regulatory configurations that favor growth. Yellow pigmentation in mutant trout arises from complex and dynamic interactions among genes involved in carotenoid, pteridine, and melanin pathways (Wu et al., 2022).

Importantly, neither albino strain examined here can be classified as a true albino phenotype. Both could be better described as “non-true albinos,” as red eye pigmentation is restricted to early developmental stages. Progressive darkening of the eyes during growth likely alters photic sensitivity, a key regulator of growth and endocrine signaling in teleosts (Sun et al., 2023).

Transcriptomic analyses of pigmentation mutants in rainbow trout provide mechanistic support for the observed phenotypic differences (Wu et al., 2022). Yellow mutants exhibit activation of pteridine and carotenoid metabolic pathways alongside differential regulation of melanogenesis-related genes, which may underpin the enhanced growth performance observed in the yellow-albino strain. In contrast, albino phenotypes characterized by dysregulated pigmentary and metabolic pathways are commonly associated with growth impairment. White-albino trout lack melanophores and display a reduced abundance of xanthophores, a phenotype linked to decreased body mass (Hattori et al., 2020). This reduction is attributed to an allele likely affecting hypothalamus–pituitary–thyroid (HPT) axis regulation, potentially involving upstream genes such as *tshb* and *trh* (Hattori et al., 2020).

Collectively, these findings support the existence of gene–gene interactions and epistatic effects governing pigmentation phenotypes and their functional coupling to growth performance. Pigmentation thus emerges not merely as a visible trait, but as an integrative physiological marker with direct implications for metabolism, growth efficiency, and aquaculture productivity, reinforcing its potential utility as a target in selective breeding programs.

To the best of our knowledge, these findings represent the first to employ the Gompertz growth curve to evaluate the performance of rainbow trout (*Oncorhynchus mykiss*) strains with distinct pigmentation patterns. Based on the application of the Gompertz model, the weight and age values at the highest inflection point, as well as the absolute growth rates observed in the white-albino and yellow-albino strains (Table 4), may be attributed to higher estimated asymptotic values (parameter A), which, in turn, result from greater variability in batch weights leading to wider confidence intervals for the model parameters. The presence of early maturing males may have influenced the data at the end of the experimental period (270 days). They accounted for 21 % of the sampled fish and may have contributed to the high variability observed in the dataset, particularly within the yellow-albino and white-albino strains.

## 5. Conclusion

Skin pigmentation is associated to the performance of rainbow trout (*Oncorhynchus mykiss*) strains, with the yellow-albino strain standing out for its superior growth and feed conversion efficiency. The Gompertz model demonstrated effective in characterizing the growth curves of wild-type, cobalt-blue, yellow-albino, and white-albino strains, providing reliable estimates of productive parameters. These findings reinforce the importance of phenotypic and genotypic selection in aquaculture and highlight the need for further research into the factors limiting the performance of the white-albino strain.

## CRedit authorship contribution statement

**Vinicius Vasconcelos Silva:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Investigation, Formal analysis. **Marcos Vinicius Bozzo Diório:** Methodology, Formal analysis, Data curation. **Vander Bruno dos Santos:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation. **Neuza Sumico Takahashi:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Formal analysis. **Yara Aiko Tabata:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology,

Investigation, Formal analysis. **Carolina Pereira de Moraes Faria:** Visualization, Software, Formal analysis, Data curation. **Antônio Carlos Kida Filho:** Software, Formal analysis, Data curation.

## Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Vinicius Vasconcelos Silva reports financial support was provided by State of Sao Paulo Research Foundation. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Data availability

Data will be made available on request.

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