EFFECTS OF DIFFERENT CULTURING DENSITIES ON THE GROWTH OF JUVENILE RAINBOW TROUT AND JUVENILE GOLDEN TROUT UNDER TEMPERATURE CONTROL SYSTEM BY GROUND SOURCE HEAT PUMP

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Abstract. A ground source heat pump temperature control system was used to increase the water temperature of northern winter trout seedling cultivation, and effects of different culturing densities on the growth of juvenile rainbow trout were examined. There were 24 groups including four density groups in each group A and B, and three parallel groups in each group, the culture experiments were carried out for 60 days and 50 days, respectively. Body weight and body length were measured every 10 days during the test, and the feed intake was recorded. The results showed that the final body weight, final body length, daily weight gain, net yield, weight gain ratio, length gain ratio, body weight specific growth ratio, and body length specific growth ratio of group A and B all decreased, as the culturing density increased. In the end of the experiment, the growth dispersion of each density group in group A was significantly different ($P < 0.05$), and the dispersion degree of group A2 was the lowest. In group B, there was significant difference in growth dispersion between lower density group and higher density group ($P < 0.05$), and the lowest appeared in group B2. With the increase of density, the feed coefficient of each density group increased, and the feed conversion ratio of A2 group and B2 group were the highest. When the temperature of the ground source heat pump was raised to 12~14 °C, the optimal culture density of

juvenile rainbow trout was 400 ind./m^3 (3.5 kg/m^3), and the optimal culture density of juvenile golden trout was 1500 ind./m^3 (2.91 kg/m^3).
Keywords: *temperature control, cold water fish, fry, aquaculture, ecological environment*

Introduction

Rainbow trout (*Oncorhynchus mykiss*), native to the Pacific coast of North America, is a rare cold water fish with high economic and edible value. It is one of the first fish to be cultured artificially, adult rainbow trout can weigh about 2.8 kg (Gharbi, 2000; Federici et al., 2007; Vinson and Baker, 2008). Because the meat is fresh and tender, delicious, with no fishy taste/smell, no intermuscular spines, and comprehensive nutrition (Bureau et al., 1999; Biro et al., 2004; Yano et al., 2012). In addition, after years of domestication, some excellent varieties have been formed, which are highly suitable for intensive industrialized culture, making rainbow trout one of the economic fish highly recommended by the world Food and Agriculture Organization (Siwicki et al., 1994; Wang, 2013b; Swartzman and Beauchamp, 2017). Golden trout is a variant of rainbow trout, similar with rainbow trout in age and size (Refstie et al., 2000). It not only has high nutritional value like rainbow trout, but also has high ornamental value (Yann et al., 1999; Wang, 2013). With the development of social economy and the improvement of living standards, trout will become an important protein source for people, which will inevitably promote the development of trout aquaculture (Kierkegaard et al., 1999; Rexroad et al., 2008). Lakes and reservoirs are scattered all over the north of China, with mountains and streams. It is very rich in cold water resources, which is very suitable for trout culture. However, the low temperature in northern winter and low water temperature of seedling cultivation affecting the growth speed of seedlings (Fukushima et al., 2016). Therefore, it is an inevitable trend to innovate seedling cultivation mode, improve culturing technology in all links, and realize high-yield, efficient, economic and environmental friendly healthy culturing (Pavlov et al., 2000; Wang et al., 2020).

The culturing period of trout is mostly in autumn and winter. After culturing, it is restricted by the cold temperature in the north of China (7 ~ 9 °C), and the low culturing water temperature will affect the growth of juvenile trout. Wang et al. (2017) have shown that meteorological conditions have an obvious impact on cold water fish culture. Li (2021) explained in the culturing conditions of triploid rainbow trout that when the water temperature is lower than 8 °C, the metabolism level of fish decreases, the feeding becomes less or no, and the growth speed becomes very slow. Yang et al. (2016) Carried out the effect of water temperature on the growth of all female rainbow trout juveniles, indicating that appropriately increasing the culturing water temperature during the seedling period will effectively improve the growth rate of rainbow trout. Therefore, it is imperative to improve the culturing water temperature of trout at the seedling stage.

Ground source heat pump is a device that transfers land shallow energy from low-grade heat energy to high-grade heat energy by inputting a small amount of high-grade energy (such as electric energy) (Ozgener and Hepbasli, 2005; Omer, 2008; Cai et al., 2014). In aquaculture, using ground source heat pump seedling pond temperature regulation system has obvious advantages, low operation cost, environmental protection, safety, reliability, high efficiency and stability (Lund et al., 2011; Dan, 2013). Using ground source heat pump to raise seedlings can not only meet the needs of regulating culturing water temperature, but also meet the national strategic requirements for the sustainable development of national economy (Wang, 2013a). In exploring the

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application of heat pump technology in agriculture, Wang et al. (2020) expounded the application experience of ground source heat pump in aquaculture. However, the effects of different culture densities on the growth of juvenile trout under the condition of using ground source heat pump to improve the culture water temperature in winter have not been reported. Due to the low temperature in winter in the northern alpine areas, the growth rate of trout cultured at normal room temperature is bound to accelerate after using ground source heat pump to raise to a certain temperature. If we cannot correctly grasp the culturing density, it is very easy to cause the disease, hypoxia and poor growth of juvenile fish (Ehulka et al., 2020; Ljabc et al., 2020). Therefore, under the intervention of ground source heat pump, it is very necessary to explore a reasonable stocking density in order to obtain higher economic benefits.

In this study, the effects of different culture densities on the growth of rainbow trout and golden trout juveniles were carried out under the temperature raising of ground source heat pump, in order to explore the reasonable stocking density and provide scientific reference for the temperature raising of trout by ground source heat pump.

Materials and methods

Test material

Experimental fish

The experimental rainbow trout juveniles were developed by the cold water fish research group of Fisheries Branch of Harbin academy of Agricultural Sciences after years of careful cultivation.

In the early stage of the experiment, rainbow trout was artificially bred to obtain eye eggs. After the fry floated, they were fed for three months. 90-day-old juveniles with consistent specifications and healthy physique were selected as the experimental fish and recorded as group A.

The juvenile golden trout for the experiment was introduced from the cold water fish farm in Liaoyang City, Liaoning Province. After artificial incubation, cultivation and feeding for one and a half months, the 50-day-old juvenile fish with similar specifications were selected as the experimental fish and recorded as group B.

Juvenile fish feed

The feed used in the experiment was the special particle compound feed for fish fry produced by Shandong Shengsuo fishery feed research center. The guaranteed values of main components were: crude protein ≥ 50.0%, crude fat ≥ 8.0%, crude fiber ≤ 3.0%, crude ash ≤ 16.5%, lysine ≥ 2.0%, calcium ≤ 5.0%, total phosphorus ≥ 1.0% and water ≤ 12%.

Ground source heat pump control system

The ground source heat pump control system is produced by Shenyang Kehua Pump Industry Co., Ltd. during winter operation, record the ground source heat pump temperature and outdoor air temperature, culturing shed temperature, culturing water temperature and normal culturing water temperature after the ground source heat pump is lifted. The daily temperature records during the comprehensive test summarize the average temperatures of the three observation time points (*Table 1*). It can be seen from

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Table 1 that the culturing water temperature increased by ground source heat pump is 12 ~ 14 °C, while the normal culturing water temperature is 8 ~ 9 °C. Therefore, the culturing water temperature in this study was 12 ~ 14 °C.

Table 1. *Outdoor air temperature, culturing shed temperature, ground source heat pump temperature and culturing water temperature (°C). All data were averages of the study period*

	Ground source heat pump operating temperature		
Daily observation time point	4:00am	1:00pm	10:00pm
Outdoor air temperature	-22	-18	-30
culturing shed temperature	15	20	15
External circulation effluent temperature	8.8	3.3	4.3
External circulation water inlet temperature	8.7	8.3	9.2
User side water supply temperature	33	43.3	42.1
Return water at user side temperature	33.1	38.3	37.4
Exhaust temperature	37.8	62	60.7
Suction temperature	8.4	5	4.3
Spray temperature	37.8	62	60.7
Temperature in electric box	15.2	16.7	19.7
Heat pump culturing water temperature	12	14	13
Normal culturing water temperature	8	9	8.5

Experimental design

Two groups of juveniles A and B will carry out culturing trials at the same time from January 21, 2021. Group A (rainbow trout juveniles) will be carried out for 60 days, and group B (golden trout juveniles) will be farmed for 50 days. Before the juvenile test, weigh the body mass and body length. The initial average body weight of juveniles in group A was 8.75 ± 0.09 g and the initial average body length was 7.88 ± 0.04 cm, the initial average body weight of juveniles in group B was 1.94 ± 0.12 g, and the initial average body length was 4.66 ± 0.15 cm.

Under the condition of ground source heat pump temperature increase, rainbow trout juveniles and golden trout juveniles are set up with 4 density gradient groups respectively, denoted as A1 (300 ind./m^3), A2 (400 ind./m^3), A3 (500 ind./m^3), A4 (600 ind./m^3) and B1 (1000 ind./m^3), B2 (1500 ind./m^3), B3 (2000 ind./m^3), B4 (2500 ind./m^3), each density group has three parallels.

Each experimental group randomly sampled once every 10 days. After the fish were anesthetized with 2-Propoxyethanol ($C_5H_{12}O_2$), their body length and weight were quickly measured. After anesthetizing the fish, quickly measure its body length and weight. Among them, group A randomly selected 50 fish from each pool each time, the test period was 60 days, and tested a total of 6 times, and group B randomly selected 100 fish from each pool each time, the test period was 50 days, and tested a total of 5 times.

Culturing test

The test pond is 24 round glass tank culture ponds with a bottom area of 2.5 m^2. Each culture pond is equipped with an inlet and an outlet at the center of the bottom, and the water depth is controlled at 0.28 m. The experiment adopts micro-flow aquaculture

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(average water velocity is 6.175 × 10^{-3} L/s), natural light, and the temperature of the culture water after raising the temperature by the ground source heat pump reaches 12-14 °C. Measure the temperature and dissolved oxygen of the culturing water twice a day in the morning and evening to ensure that the dissolved oxygen in the water body is higher than 6 mg/L.

The test fish that died during the culturing process were taken out in time. In order to maintain the test culturing density, fish of the same size were selected from the reserve group to supplement, and records were made.

During the test period, the bait was given twice a day at regular intervals, and the daily amount and the total fish food supply were calculated according to the body mass of the fish and adjusted according to the actual food intake. Discharge sewage 1 to 2 times a day, change the water appropriately according to the actual situation each time, and change the water to maintain a temperature difference of ± 0.5 °C. Check the food intake and activity status of the test fish daily, check fish diseases regularly, and make various records. The waste feed was collected.

Data analysis

$$\text{Daily weight gain (DWG, g / d)} = (W_2 - W_1) / (t_2 - t_1) \quad \text{(Eq.1)}$$

$$\text{Net yield [NY, g / (m}^2\cdot\text{d)]} = (W_2 / S - W_1 / S) / (\mathrm{t}_2 - t_1) \quad \text{(Eq.2)}$$

$$\text{Weight gain ratio (WG, \%)} = 100 \times (W_2 - W_1) / W_1 \quad \text{(Eq.3)}$$

$$\text{Length gain ratio (LG, \%)} = 100 \times (L_2 - L_1) / L_1 \quad \text{(Eq.4)}$$

$$\text{Specific growth rate of weight (SGRW, \%/d)} = 100 \times (\ln W_2 - \ln W_1) / (t_2 - t_1) \quad \text{(Eq.5)}$$

$$\text{Specific growth rate of length (SGRL, \%/d)} = 100 \times (\ln L_2 - \ln L_1) / (t_2 - t_1) \quad \text{(Eq.6)}$$

$$\text{Coefficient of variability weight (CVW, \%)} = 100 \times SD_{\mathrm{w}} / W \quad \text{(Eq.7)}$$

$$\text{Coefficient of variability length (CVL, \%)} = 100 \times SD_{\mathrm{L}} / L \quad \text{(Eq.8)}$$

$$\text{Feeding ratio (FR, \%/d)} = 200 \times F / [(W_2 + W_1)n(t_2 - t_1)] \quad \text{(Eq.9)}$$

$$\text{Feeding coefficient (FC)} = F / [\, n\, (W_2 - W_1)] \quad \text{(Eq.10)}$$

$$\text{Feeding conversion ratio (FCR, \%)} = 100 \times n\, (W_2 - W_1) / F \quad \text{(Eq.11)}$$

$$\text{Condition factor (K, \%}\cdot\text{g/cm}^3) = 100 \times W / L^3 \quad \text{(Eq.12)}$$

$$\text{Survival rate (SR, \%)} = 100 \times N_2 / N_1 \quad \text{(Eq.13)}$$

$$\text{Body length growth equation, } L = a' + b't \quad \text{(Eq.14)}$$

$$\text{Body mass growth equation, } W = a'\,\mathrm{e}^{b't} \quad \text{(Eq.15)}$$

$$\text{Body length mass relationship equation, } W = a'\,L^{b'} \quad \text{(Eq.16)}$$

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where W is the average body weight (g), L is the average body length (cm), t is the test days (d), W_1 and W_2 are the body weight at t_1 and t_2 (g), SD_w is the standard deviation of body weight, SD_L is the standard deviation of body length, S is the area of aquaculture pond (m^2), F is the total amount of bait (g), n is the number of test fish tails, N_1 and N_2 are the initial number of tails and end number of the test respectively, a' and b' are constants.

The test data was analyzed and processed using SPSS25.0 software and Excel 2007. One-way ANOVA analysis of variance was performed on the measurement data, and Duncan's multiple comparisons were performed between groups. $P < 0.05$ was used as the standard of significant difference, and $P < 0.01$ was the difference and its significance standard. The test results were based on the mean ± standard error. Use the curve regression method to analyze and calculate the relationship equations between body length, body weight and culturing days.

Results

Growth characteristics of juvenile rainbow trout in group A

Effect of culturing density on the growth index of rainbow trout juveniles

The differences in growth indicators of rainbow trout juveniles of each density group were shown in *Table 2*. The initial body weight and initial body length of rainbow trout juveniles in each density group were not significantly different. Since the 20th day, the body mass and body length of the A1 group were significantly larger than those of the other groups. By the 60th day, the body mass and body length of the density groups were significantly different ($P < 0.05$) (*Figs. 1* and 2). The regression equations of body length, body weight, and culturing days of each density group (*Table 3*). The growth rate of the body length and weight of rainbow trout juveniles decreased with the increase of culturing density, and the growth rate of group A1 was the fastest.

Table 2. *Growth indexes of juvenile rainbow trout at different densities*

Parameters	Group			
	A1 (300 ind./m^3)	A2 (400 ind./m^3)	A3 (500 ind./m^3)	A4 (600 ind./m^3)
Initial body weight (g)	8.72 ± 0.00 ^{a}	8.76 ± 0.00 ^{a}	8.80 ± 0.00 ^{a}	8.70 ± 0.00 ^{a}
Final body weight (g)	55.80 ± 10.80 ^{a}	53.23 ± 8.35 ^{b}	48.49 ± 7.15 ^{c}	44.01 ± 7.80 ^{d}
Initial body length (cm)	7.87 ± 0.00 ^{a}	7.88 ± 0.00 ^{a}	7.90 ± 0.00 ^{a}	7.86 ± 0.00 ^{a}
Final body length (cm)	14.39 ± 0.01 ^{a}	14.22 ± 0.02 ^{b}	13.96 ± 0.01 ^{c}	13.57 ± 0.01 ^{d}
DWG (g/d)	0.79 ± 0.00 ^{a}	0.74 ± 0.00 ^{b}	0.66 ± 0.01 ^{c}	0.59 ± 0.01 ^{d}
NY [g/(m^2·d)]	0.31 ± 0.00 ^{a}	0.29 ± 0.00 ^{b}	0.26 ± 0.00 ^{c}	0.23 ± 0.00 ^{d}
GBWR (%)	36.36 ± 0.05 ^{a}	35.13 ± 0.12 ^{b}	32.91 ± 0.12 ^{c}	31.04 ± 0.12 ^{d}
GBLR (%)	10.6 ± 0.01 ^{a}	10.35 ± 0.02 ^{b}	9.96 ± 0.02 ^{c}	9.52 ± 0.02 ^{d}
SGRW (%/d)	3.10 ± 0.00 ^{a}	3.01 ± 0.01 ^{b}	2.84 ± 0.01 ^{c}	2.70 ± 0.01 ^{d}
SGRL (%/d)	1.01 ± 0.00 ^{a}	0.98 ± 0.00 ^{b}	0.95 ± 0.00 ^{c}	0.91 ± 0.00 ^{d}

In the same row, values with same small letters superscripts mean no significant differences ($P > 0.05$), different small letters lowercase letters superscripts mean significant differences ($P < 0.05$). The same as the following

DWG: Daily weight gain, NY: Net yield, GBWR: Gain body weight rate, GBLR: Growth body length rate, SGRW: Specific growth rate of weight, SGRL: Specific growth rate of length

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Table 3. *The regression equations of body length, body weight and culture days of juvenile rainbow trout of each culturing density group*

Group	Regression equations of *L-t*		Regression equations of *W-t*		Regression equations of *W-L*	
	Equation	R^2	Equation	R^2	Equation	R^2
A1(300 ind./m^3)	$L_{A1} = 0.109t + 7.754$	0.998	$W_{A1} = 9.225e^{0.030t}$	0.996	$W_{A1} = 0.0153L^{3.081}$	0.999
A2(400 ind./m^3)	$L_{A2} = 0.105t + 7.675$	0.995	$W_{A2} = 8.976e^{0.030t}$	0.999	$W_{A2} = 0.0159L^{3.061}$	0.999
A3(500 ind./m^3)	$L_{A3} = 0.101t + 7.664$	0.993	$W_{A3} = 8.917e^{0.029t}$	0.999	$W_{A3} = 0.0178L^{3.009}$	0.999
A4(600 ind./m^3)	$L_{A4} = 0.096t + 7.656$	0.995	$W_{A4} = 8.855e^{0.027t}$	0.999	$W_{A4} = 0.0196L^{2.964}$	0.999

A1, A2, A3 and A4: group A1 A2, A3 and A4, respectively

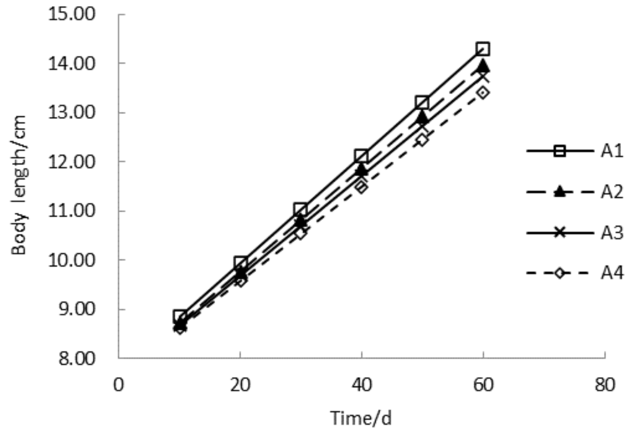

Figure 1. *Relationship between body length and culture days of juvenile rainbow trout at different densities. A1 (300 ind./m^3), A2 (400 ind./m^3), A3 (500 ind./m^3) and A4 (600 ind./m^3): group A1 A2, A3 and A4, respectively*

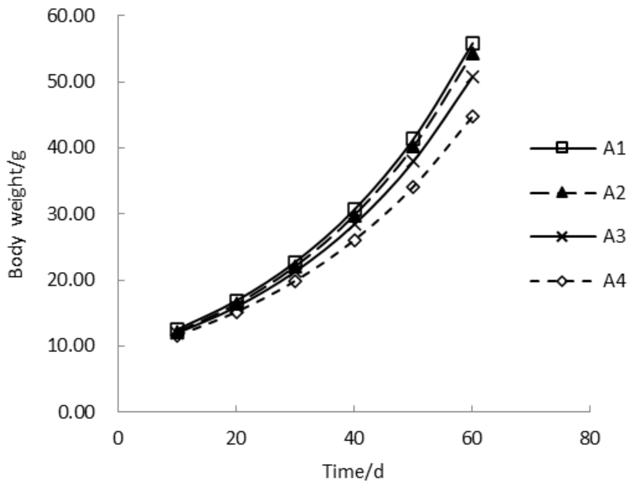

Figure 2. *Body weight growth curves of juvenile rainbow trout at different densities. A1 (300 ind./m^3), A2 (400 ind./m^3), A3 (500 ind./m^3) and A4 (600 ind./m^3): group A1 A2, A3 and A4, respectively*

The daily weight gain, net weight, weight gain ratio, length growth rate, specific growth rate of weight, and specific growth rate of length of rainbow trout juveniles all

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decrease with the increase of culturing density. Among them, group A1 observed the largest value, which are DWG (0.79 ± 0.00 g/d), NY [0.31 ± 0.00 g/(m^2·d)], GBWR (36.36 ± 0.05%), GBLR (10.6 ± 0.01%), SGRW (3.10 ± 0.00%/d), SGRL (1.01 ± 0.00%/d), there were significant differences between the density groups ($P < 0.05$).

Effect of culturing density on the growth dispersion of rainbow trout juveniles

The coefficient of variation of body mass of rainbow trout juveniles of different density groups was different in different culturing periods (*Table 4*). The coefficient of variation of body weight in groups A1, A2, and A4 was the smallest on the 30th day, and then as the culturing time increased, the coefficient of variation gradually increased, and the coefficient of variation became smaller on the 60th day. During the test periods, the maximum body mass dispersion appeared in group A1 (22.95%) on the 50th day. At the end of the experiment, there was a significant difference in the coefficient of variation of body mass between the density groups ($P < 0.05$), among which the value of group A2 was the lowest (17.09%), the coefficient of variation of final body mass in group A4 was the largest (20.71%), and the difference in growth dispersion was the largest.

Table 4. *Coefficient variation in body weight under different culture time of juvenile rainbow trout of each culturing density group (CVW, %)*

Group	**Culturing days**					
	10	**20**	**30**	**40**	**50**	**60**
A1(300 ind./m^3)	19.45 ± 0.05 [a]	19.34 ± 0.07 [c]	14.95 ± 0.02 [d]	16.69 ± 0.03 [d]	22.95 ± 0.12 [a]	17.90 ± 0.04 [c]
A2(400 ind./m^3)	17.76 ± 0.06 [c]	19.94 ± 0.02 [b]	17.10 ± 0.12 [c]	17.90 ± 0.08 [c]	17.72 ± 0.08 [d]	17.09 ± 0.09 [d]
A3(500 ind./m^3)	16.50 ± 0.04 [d]	19.47 ± 0.03 [d]	18.45 ± 0.01 [a]	18.59 ± 0.03 [b]	18.08 ± 0.14 [c]	18.81 ± 0.10 [b]
A4(600 ind./m^3)	18.38 ± 0.02 [b]	20.31 ± 0.00 [a]	17.70 ± 0.13 [b]	20.17 ± 0.08 [a]	21.65 ± 0.07 [b]	20.71 ± 0.12 [a]

A1, A2, A3 and A4: group A1 A2, A3 and A4, respectively

The body length variation coefficient of rainbow trout juveniles in each density group is shown in *Table 5*. During the experiment, the minimum body length dispersion appeared in group A2 (5.25%) on the 40th day. At the end of the experiment, there was a significant difference in the coefficient of variation of body length between the density groups ($P < 0.05$), with the lowest value in the A2 group (5.55%) and the highest value in the A4 group (6.69%).

Table 5. *Coefficient variation in body length under different culture time of juvenile rainbow trout of each culturing density group (CVL, %)*

Group	**Culturing days**					
	10	**20**	**30**	**40**	**50**	**60**
A1(300 ind./m^3)	8.16 ± 0.01 [a]	6.30 ± 0.01 [d]	5.62 ± 0.01 [d]	6.19 ± 0.01 [a]	6.66 ± 0.01 [a]	5.67 ± 0.01 [c]
A2(400 ind./m^3)	7.33 ± 0.01 [c]	6.43 ± 0.01 [c]	5.75 ± 0.01 [c]	5.25 ± 0.01 [d]	6.06 ± 0.01 [d]	5.55 ± 0.01 [d]
A3(500 ind./m^3)	6.98 ± 0.00 [d]	7.77 ± 0.01 [a]	5.82 ± 0.00 [b]	5.63 ± 0.01 [c]	6.31 ± 0.01 [b]	6.26 ± 0.01 [b]
A4(600 ind./m^3)	7.82 ± 0.00 [b]	6.76 ± 0.00 [b]	5.91 ± 0.01 [a]	6.05 ± 0.01 [b]	6.23 ± 0.01 [c]	6.69 ± 0.01 [a]

A1, A2, A3 and A4: group A1 A2, A3 and A4, respectively

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Effect of culturing density on the feeding, condition factor and survival rate of rainbow trout juveniles

The feeding status, fatness and survival rate of rainbow trout juveniles in each density group are shown in *Table 6*. Total food intake increases with the increase of culturing density. The feeding rate value was highest in group A4 (2.9%) and lowest in group A2 (2.68%). The feed coefficient and feed conversion rate between the A1 and A2 groups were not significantly different ($P > 0.05$), while were significantly different from the A3 and A4 groups ($P < 0.05$). Among them, the A1 group had the lowest feed coefficient (0.89), and the A2 group had the lowest feed coefficient (0.89). The feed conversion rate value is the highest (113.86%). The final condition factor decreased with the increase of the culturing density. There was no significant difference between the A1 and A2 groups ($P > 0.05$), which was significantly different from the A3 and A4 groups (P < 0.05). There was no significant difference in the survival rate between the density groups ($P > 0.05$), and the A2 composition had the highest survival rate (99.52%).

Table 6. *Feeding, condition factor and survival rate of rainbow trout juveniles of each culturing density group*

Group	Total food intake (TF/g)	Feeding rate (FR/%)	Feeding coefficient (FC)	Feed conversion rate (FCR/%)	Initial condition factor (IK/%)	Final condition factor (FK/%)	Survival rate (SR/%)
A1(300 ind./m^3)	8853.5	2.72 ± 0.00^b	0.89 ± 0.00^c	113.47 ± 0.17^a	1.79 ± 0.00^a	1.87 ± 0.00^a	99.36 ± 0.16^a
A2(400 ind./m^3)	10555	2.68 ± 0.00^c	0.90 ± 0.00^c	113.86 ± 0.44^a	1.79 ± 0.00^a	1.85 ± 0.00^a	99.52 ± 0.12^a
A3(500 ind./m^3)	12722	2.73 ± 0.01^b	0.96 ± 0.01^b	105.51 ± 0.63^b	1.79 ± 0.00^a	1.78 ± 0.01^b	99.14 ± 0.16^a
A4(600 ind./m^3)	15409.5	2.90 ± 0.01^a	1.08 ± 0.01^a	93.82 ± 0.59^c	1.79 ± 0.00^a	1.76 ± 0.00^b	99.21 ± 0.21^a

A1, A2, A3 and A4: group A1 A2, A3 and A4, respectively

Growth characteristics of juvenile golden trout in group B

Effect of culturing density on the growth index of golden trout juveniles

The difference in growth index of golden trout juveniles in each density group is shown in *Table 7*. The initial body weight and initial body length of golden trout juveniles in each density group were not significantly different ($P > 0.05$), and the growth rate of each density group was not significantly different at the beginning of the experiment. From the 20th day to the 50th day, the body length of the B1 group was significantly larger than that of the other groups, showing a significant difference ($P < 0.05$) (*Fig. 3*). From the 30th day to the end of culturing, the body weight of each density group showed significant differences ($P < 0.05$) (*Fig. 4*). The regression equation between body length, body mass and culturing days of each density group is shown in *Table 8*. The growth rate of body length and weight of golden trout juveniles decreased with the increase of culturing density, and the growth rate of group B1 was the fastest. At the end of the experiment, the body mass and body length of the B1 group reached their maximum values, which were 13.91 ± 0.58 g and 8.80 ± 0.15 cm, respectively. There was no significant difference between the B3 and B4 groups ($P > 0.05$).

The daily weight gain, net weight, weight gain ratio, length growth rate, specific growth rate of weight, and specific growth rate of length of golden trout juveniles all decrease with the increase of culturing density. Among them, group B1 has the largest

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value, which is significantly different from other groups ($P < 0.05$). The values of group B1 are DWG (0.24 ± 0.01 g/d), NY [0.09 ± 0.00 g/(m²·d)], GBWR (48.82 ± 1.12)%, GBLR (13.53 ± 0.39)%, SGRW (3.93 ± 0.08%/d), SGRL (1.27 ± 0.03%/d).

Table 7. *Growth indexes of juvenile golden trout at different densities*

Parameters	Group			
	B1 (1000 ind./m³)	**B2 (1500 ind./m³)**	**B3 (2000 ind./m³)**	**B4 (2500 ind./m³)**
Initial body weight (g)	1.95 ± 0.01 [a]	1.94 ± 0.01 [a]	1.93 ± 0.01 [a]	1.94 ± 0.01 [a]
Final body weight (g)	13.91 ± 0.58 [a]	11.76 ± 0.42 [b]	9.77 ± 0.33 [c]	8.84 ± 0.41 [c]
Initial body length (cm)	4.67 ± 0.01 [a]	4.67 ± 0.01 [a]	4.65 ± 0.01 [a]	4.66 ± 0.01 [a]
Final body length (cm)	8.80 ± 0.15 [a]	8.26 ± 0.09 [b]	7.85 ± 0.14 [bc]	7.57 ± 0.11 [c]
DWG (g/d)	0.24 ± 0.01 [a]	0.20 ± 0.01 [b]	0.16 ± 0.01 [c]	0.14 ± 0.01 [c]
NY [g/(m²·d)]	0.09 ± 0.00 [a]	0.08 ± 0.00 [b]	0.06 ± 0.00 [c]	0.05 ± 0.00 [c]
GBWR (%)	48.82 ± 1.12 [a]	44.31 ± 1.2 [b]	41.47 ± 0.72 [bc]	38.02 ± 1.4 [c]
GBLR (%)	13.53 ± 0.39 [a]	12.12 ± 0.27 [b]	11.2 ± 0.39 [bc]	10.33 ± 0.32 [c]
SGRW (%/d)	3.93 ± 0.08 [a]	3.60 ± 0.07 [b]	3.24 ± 0.07 [c]	3.02 ± 0.09 [c]
SGRL (%/d)	1.27 ± 0.03 [a]	1.14 ± 0.02 [b]	1.04 ± 0.04 [c]	0.97 ± 0.03 [c]

DWG: Daily weight gain, NY: Net yield, GBWR: Gain body weight rate, GBLR: Growth body length rate, SGRW: Specific growth rate of weight, SGRL: Specific growth rate of length

Table 8. *The regression equations of body length, body weight and culture days of juvenile golden trout of each culturing density group*

Group	Regression equations of *L-t*		Regression equations of *W-t*		Regression equations of *W-L*	
	Equation	**R²**	**Equation**	**R²**	**Equation**	**R²**
B1(1000 ind./m³)	$L_{B1} = 0.083t + 4.607$	0.999	$W_{B1} = 2.099e^{0.039t}$	0.987	$W_{B1} = 0.0163\ L^{3.116}$	0.995
B2(1500 ind./m³)	$L_{B2} = 0.069t + 4.623$	0.993	$W_{B2} = 2.043e^{0.036t}$	0.984	$W_{B2} = 0.0135\ L^{3.226}$	0.991
B3(2000 ind./m³)	$L_{B3} = 0.070t + 4.680$	0.967	$W_{B3} = 2.170e^{0.035t}$	0.931	$W_{B3} = 0.0170\ L^{3.103}$	0.995
B4(2500 ind./m³)	$L_{B4} = 0.061t + 4.815$	0.971	$W_{B4} = 2.201e^{0.032t}$	0.927	$W_{B4} = 0.0126\ L^{3.259}$	0.988

B1, B2, B3 and B4: group B1, B2, B3 and B4

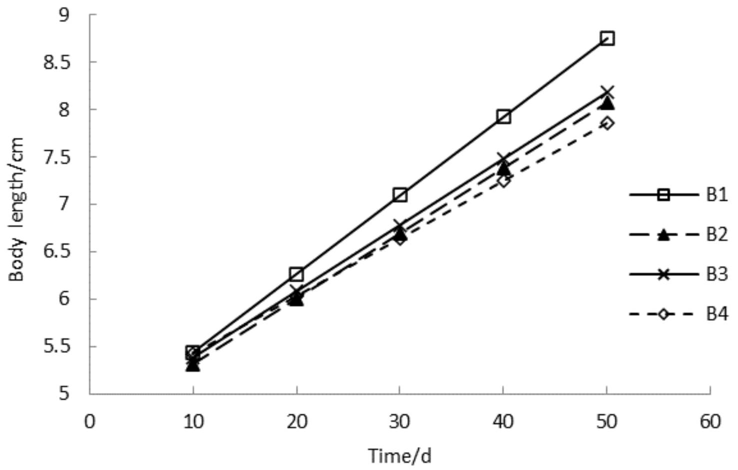

Figure 3. *Relationship between body length and culture days of juvenile golden trout at different densities. B1 (1000 ind./m³), B2 (1500 ind./m³), B3 (2000 ind./m³) and B4 (2500 ind./m³): group B1, B2, B3 and B4*

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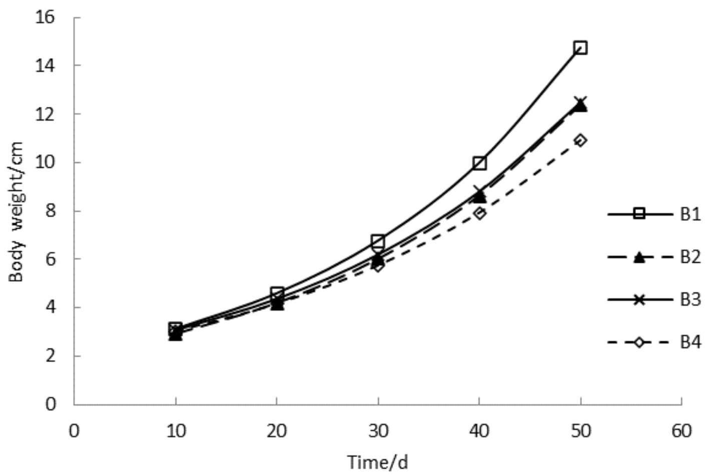

Figure 4. *Body weight growth curves of juvenile golden trout at different densities. B1 (1000 ind./m^3), B2 (1500 ind./m^3), B3 (2000 ind./m^3) and B4 (2500 ind./m^3): group B1, B2, B3 and B4*

The weight gain rate and length growth ratio of the B2 group were not significantly different from those of the B3 group ($P > 0.05$). The daily weight gain, net yield, specific growth rate of weight, and specific growth rate of weight were significantly different from those of the B3 and B4 groups ($P < 0.05$). There was no significant difference between the B3 and B4 groups ($P > 0.05$).

Effect of culturing density on the growth dispersion of golden trout juveniles

The body mass variation coefficient and body length variation coefficient of golden trout juveniles in each density group are shown in *Tables 9* and 10, respectively. At the end of the experiment, there were significant differences between the B1 and B2 groups and the B3 and B4 groups ($P < 0.05$). Among them, the B2 group had the lowest coefficient of variation of body mass and body length, which were 21.84% and 8.39%, respectively. The coefficient of variation of each density group is different in different culturing periods. With the increase of culturing density, the final coefficient of variation of body weight in group B4 is the largest, and the difference in growth dispersion is the largest. The change trend of group B1 and group B2 was the same, and the coefficient of variation was the smallest on the 20th day. After that, the coefficient of variation gradually increased with the extension of the culturing time, and the coefficient of variation became smaller on the 50th day. The body mass variation coefficients of B3 and B4 groups were the smallest on the 30th day.

Table 9. *Coefficient variation in body weight under different culture time of juvenile golden trout of each culturing density group (CVW, %)*

Group	Culturing days				
	10	20	30	40	50
B1(1000 ind./m^3)	23.17 ± 0.81 ^{b}	19.11 ± 0.66 ^{b}	19.51 ± 0.17 ^{ab}	22.34 ± 0.62 ^{b}	22.20 ± 0.92 ^{b}
B2(1500 ind./m^3)	22.78 ± 0.46 ^{b}	19.99 ± 0.91 ^{ab}	20.95 ± 0.98 ^{a}	28.03 ± 0.83 ^{a}	21.84 ± 0.80 ^{b}
B3(2000 ind./m^3)	25.83 ± 1.45 ^{b}	18.68 ± 0.56 ^{b}	15.02 ± 0.09 ^{c}	25.84 ± 1.28 ^{a}	25.97 ± 0.89 ^{a}
B4(2500 ind./m^3)	29.06 ± 0.69 ^{a}	21.59 ± 0.70 ^{a}	18.14 ± 0.33 ^{b}	29.32 ± 1.27 ^{a}	28.39 ± 1.27 ^{a}

B1, B2, B3 and B4: group B1, B2, B3 and B4

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Table 10. *Coefficient variation in body length under different culture time of juvenile golden trout of each culturing density group (CVW, %)*

Group	Culturing days				
	10	20	30	40	50
B1(1000 ind./m^3)	8.77 ± 0.17 ^{c}	6.48 ± 0.06 ^{a}	7.37 ± 0.01 ^{b}	7.86 ± 0.07 ^{b}	8.50 ± 0.14 ^{b}
B2(1500 ind./m^3)	9.72 ± 0.07 ^{b}	6.69 ± 0.10 ^{a}	7.71 ± 0.13 ^{a}	8.78 ± 0.01 ^{a}	8.39 ± 0.10 ^{b}
B3(2000 ind./m^3)	9.63 ± 0.17 ^{b}	6.61 ± 0.05 ^{a}	6.14 ± 0.11 ^{d}	8.59 ± 0.17 ^{a}	9.50 ± 0.17 ^{a}
B4(2500 ind./m^3)	10.50 ± 0.13 ^{a}	6.09 ± 0.07 ^{b}	6.57 ± 0.06 ^{c}	8.85 ± 0.09 ^{a}	9.38 ± 0.13 ^{a}

B1, B2, B3 and B4: group B1, B2, B3 and B4

Effect of culturing density on the feeding, condition factor and survival rate of golden trout juveniles

The feeding status, condition factor and survival rate of golden trout juveniles in each density group are shown in *Table 11*. The total food intake increases with the increase of culturing density. The food intake rate of the B1 and B2 groups was significantly different from that of the B3 and B4 groups ($P < 0.05$), and the B2 group had the highest value (2.68%). The feed coefficient increased with the increase of culturing density, and the feed coefficient of group B1 was the smallest (0.7). The feed conversion rate decreased with the increase of density, and there was a significant difference between the B1, B3 and B4 groups ($P < 0.05$). There was no significant difference in terminal fatness between the density groups ($P > 0.05$), and the B2 group had the highest value (2.09%). B2 group had the highest compositional survival rate (99.81%), which was significantly different from the B3 and B4 groups (P < 0.05).

Table 11. *Feeding, condition factor and survival rate of golden trout juveniles of each culturing density group*

Group	Total food intake (TF/g)	Feeding rate (FR/%)	Feeding coefficient (FC)	Feed conversion rate (FCR/%)	Initial condition factor (IK/%)	Final condition factor (FK/%)	Survival rate (SR/%)
B1 (1000 ind./m^3)	5702	2.60±0.06 ^{a}	0.70±0.05 ^{c}	148.08±6.44 ^{a}	1.91±0.02 ^{a}	2.04±0.03 ^{a}	99.71±0.08 ^{ab}
B2 (1500 ind./m^3)	7515	2.68±0.08 ^{a}	0.90±0.05 ^{bc}	132.66±6.14 ^{ab}	1.91±0.01 ^{a}	2.09±0.01 ^{a}	99.81±0.05 ^{a}
B3 (2000 ind./m^3)	8367	2.29±0.06 ^{b}	1.23±0.13 ^{b}	127.19±4.13 ^{b}	1.92±0.01 ^{a}	2.03±0.04 ^{a}	99.02±0.23 ^{c}
B4 (2500 ind./m^3)	9998	2.31±0.06 ^{b}	1.46±0.15 ^{a}	114.65±6.47 ^{b}	1.92±0.02 ^{a}	2.04±0.01 ^{a}	99.27±0.18 ^{bc}

B1, B2, B3 and B4: group B1, B2, B3 and B4

Discussion

Effects of different culture densities on the growth of rainbow trout juveniles under the intervention of ground source heat pump temperature control system

Culture density is one of the important factors affecting the growth and survival of fish (Altamirano et al., 2021; Florencia et al., 2021; Mbalaka et al., 2012). The growth characteristics of fish in different growth periods are different, especially in the juvenile period, the growth of fish fluctuates greatly, which has an important impact on its later growth (Lan and Luo, 1995; Mu et al., 2005). The higher the culture density of juvenile fish, the relative reduction of its activity space. Meanwhile, its growth rate will be restricted due to the interaction of a series of environmental factors (Deng et al., 2005;

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Bolasina et al., 2006). Juveniles exposed to community and environmental stress will spontaneously change their internal physiological state in order to adapt to environmental changes (Hori et al., 2008). When the external pressure exceeds its physiological regulation limit, it will have adverse effects on the fish body, resulting in the growth retardation of juveniles (Liao et al., 2006). In this study, the final body weight, final body length, DWG, NY, GBWR, GBLR, SGRW and SGRL of rainbow trout juveniles decreased with the increase of culturing density, and the difference between the density groups was significant. This result is consistent with the research situation of Jiang (2009) on rainbow trout juveniles. Higher culturing density will increase the competition of juvenile fish for living space and food (Ren et al., 2013). Juveniles with growth advantages will occupy more water space and bait resources (Kirsten et al., 2004). Compared with other juvenile fish living in the same space, their individual size is larger and their physique is better, which leads to a higher degree of growth dispersion in the school of fish (Sarah et al., 2005). At the end of the experimental study, the growth dispersion of rainbow trout juveniles in the lower density group A2 was the lowest, followed by the lowest density group A1, and the higher density groups A3 and A4 increased the growth dispersion in order. This result shows that when the culturing density increases and the culturing space and bait resources are limited, the growth rate of the inferior rainbow trout juveniles will be further reduced, resulting in a decrease in the overall growth rate of the fish population and increased dispersion of growth. In this experiment, the FC of rainbow trout juveniles increased with the increase of culturing density. FCR of the A2 group is the highest, and the difference between the low-density group A1 and A2 group is not significant, and it is significantly different from the A3 and A4 groups. This result indicates that the low-density group rainbow trout juveniles have a higher feed utilization rate. Rainbow trout is a group of fish with a strong group (Ibarra et al., 1994). When it lives in a group, the time spent on alert and looking for food is reduced, and the fish can quickly enter the feeding state (Barkov and Kurashov, 2011). Papoutsoglou et al. (1998) research showed that sea bass showed obvious advantages in group feeding in the cultured height group, and Leng et al. (1999) research showed that too low aquaculture density is not conducive to Russian sturgeon grabbing food. The above research results are consistent with the results in this experiment that the high-density group of rainbow trout juveniles has a higher feeding rate. When the stocking density of fish is high, the competition among fish is fierce, which is easy to increase the mechanical friction damage of the fish (Leng et al., 1999). When the experiment was carried out to about 50 days, the juvenile rainbow trout of groups A3 and A4 with higher density had different degrees of fin rotten phenomenon. The physique of rainbow trout juveniles of lower density groups A1 and A2 was good, and the A2 composition survival rate was the highest at the end of the experiment.

Effects of different culture densities on the growth of golden trout juveniles under the intervention of ground source heat pump temperature control system

Golden trout and rainbow trout are genetically related, belong to the same strain, and their growth characteristics are similar to rainbow trout (Wang et al., 2000). In this study, the final body weight, final body length, DWG, NY, GBWR, GBLR, SGRW and SGRL of rainbow trout juveniles decreased with the increase of culturing density, and the difference between the density groups was significant. The value of group B1 was the largest, and the difference between group B2 and group B1 was not significant,

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indicating that the growth rate of golden trout juveniles decreased with the increase of culturing density. At the end of the experiment, the growth dispersion degree of golden trout juveniles in the B2 density group was the lowest, followed by the lowest density group B1, and the growth dispersion degree of the golden trout juveniles was significantly different from the higher density groups B3 and B4. The increase in culturing density is exacerbated. In this experiment, FC increased with the increase in density, and the feed conversion rate decreased with the increase in density. There was no significant difference between the B1 and B2 groups in the low-density group. The low-density group has a higher feeding rate, which is significantly different from the high-density group. The B2 group has the highest value. This result is different from that of rainbow trout juveniles. It is speculated that the reason may be that the individual golden trout juveniles are smaller when stocking, and the number of stockings in each density group is larger. At the beginning of the experiment, under the same culturing space, the intensified competition of golden trout juveniles consumed a lot of energy (Fran and Daniel, 2011). Therefore, its feeding ability is enhanced to balance physical energy consumption. Although the feed conversion rate of golden trout juveniles in the high-density group is low, there is no significant difference in the terminal fatness between the density groups, and the fatness of the B2 group is relatively high. The B2 group had the highest survival rate, which was significantly different from the B3 and B4 groups. After the experiment was carried out for 40 days, the golden trout juveniles of the higher density groups B3 and B4 all appeared diseased fish with enteritis. At the same time, most juveniles began to have different degrees of fin rotten phenomenon, which led to the death of some test fish in the high-density group, and restricted the growth of some golden trout juveniles. The increased dispersion of growth in the high-density group at the end of the culture also explained this point.

Conclusions

In aquaculture production, too low stocking density is not conducive to improving economic benefits, and too high stocking density will cause slow growth of fish, fish susceptibility to disease, and low survival rate. Therefore, in order to achieve the best culturing effect, it is very important to choose a reasonable stocking density. In this study, a comprehensive comparison of aquaculture experiments concluded that under the intervention of the ground-source heat pump temperature control system, the temperature of the aquaculture water increased to 12~14 °C. We recommended that the optimal stocking density of rainbow trout juveniles is 400 ind./m^3 (3.5 kg/m^3), and the optimal stocking density of golden trout juveniles is 1500 ind./m^3 (2.91 kg/m^3).

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