



Full length article

Dietary effects of *Coriandrum sativum* extract on growth performance, physiological and innate immune responses and resistance of rainbow trout (*Oncorhynchus mykiss*) against *Yersinia ruckeri*

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ABSTRACT

This investigation was aimed to determine the efficacy of coriander seed extract (*Coriandrum sativum*) on physiological responses, immunity and disease resistance of rainbow trout, *Oncorhynchus mykiss* for eight weeks. A total number of six hundred rainbow trout (62 ± 0.81 g) were divided into four feeding groups including 0 (control), 0.5%, 1% and 2% of coriander seed extract (CSE). In the present study, rainbow trout fed with 2% of CSE showed significantly higher values of specific growth rate (SGR), final weight (FW) and condition factor (CF) in comparison with control group after eight weeks ($P < 0.05$). Regarding hematological indices results, the 2% dosage of CSE showed the highest amount of hematocrit and hemoglobin compared to control group ($P < 0.05$). In addition, significant improvement of lysozyme and alternative complement activity, were observed in 2% of CSE treatment ($P < 0.05$). After eight weeks post-feeding, 30 fish from each treatment were challenged with *Yersinia ruckeri* for 14 days. The findings presented that fish fed with CES, especially 2% of CSE inclusion, improved survival rate of rainbow trout against *Y. ruckeri*; however, there were no significant differences among the fish in control and treatment groups at the end of the eight weeks feeding with coriander seed extract. The present study demonstrated, dietary incorporation of coriander extract can improve growth factors, immunological indices and resistance of rainbow trout (*O. mykiss*) against *Y. ruckeri* infection.

1. Introduction

Aquaculture industry is the fastest growing sector of food production in the world since last decades and has been boosted due to high quality protein products (high digestibility, rich in essential amino acids, minerals and vitamins) [1,2]. However, infectious diseases outbreaks have become a prominent threat to the healthy and sustainable development of the industry [2–5].

Infectious diseases have been considered as main constraint to the aquaculture and cause serious economic losses [4–7]. Antibiotics preliminary were of farmers interest due to their benefits such as improvement of growth, food conversion ratio, survival rate, reducing disease outbreaks risk [3–7]. Nevertheless, utilization of antibiotics has resulted in the development of drug resistant strains and several drug

residues accumulating within aquatic products and consequently arising food safety concerns [7–9]. Thereby, the applications of antibiotics in aquaculture practices must be reduced or eliminated by substitution with newly developed products which are more ecofriendly to animals and environments [5–10].

Medical plants have become of great interest as an alternative approach for controlling diseases in aquaculture to reduce the side-effects of antibiotics and chemotherapeutics [7–11]. In fact, the presence of many bioactive compounds such as alkaloids, steroids, phenolics, tannins, terpenoids, saponins, glycosides, and flavonoids has been well proven in case of fish growth improvement, appetite stimulation, immune modulation, antimicrobial, and anti-stress [10–16]. The different form of medical plants have been applied in aquaculture such as crude, extracts or active compounds, as well as incorporation with a probiotic

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Table 1
Composition of seed essential extract of *C. sativum*.

Name of chemical compounds	Percentage	Name of chemical compounds	Percentage
γ-Terpinene	14.4	Terpinyl acetate	0.3
Camphene	0.1	Decanal	0.1
E-Verbenol	0.3	Z-verbenone	0.1
Sabinene	0.2	Citronellol	1.3
β-Pinene	1.8	Citral	1.4
ol,1,2,3-trimethyl	0.6	Geraniol	1.9
α-Thujene	1.2	Eugenol	0.9
m-Cymene	0.4	Carveol	0.2
Limonene	0.1	Undecanal	0.6
E-OCimene	0.2	Methyl geranate	0.2
Z-OCimene	0.2	Myrtenyl acetate	0.4
Lilac alcohol	0.1	Citronellyl acetate	1.4
α-Terpinene	0.0	Geranyl acetate	17.6
Z-Verbenol	0.1	Z-myrtanyl acetate	0.1
Linalool	37.7	β-Elementene	0.1
Isothujol	0.1	Dodecalen	0.2
α-Campholenal	0.2	Caryophyllene	0.3
Citronellal	2.0	β-Farnesene	0.1
Umbellulone	0.1	2-Dodecalen	0.2
Borneol	0.2	Curcumene	1.0
4-Terpeneol	0.1		

or with an animal product [14–16]. Previous studies showed that the use of herbal extracts such as, olive leaf (*Olea europaea*) [17], ginger (*Zingiber officinale*) [18], lupin [*Lupinus perennis*] [19], garlic (*Allium sativum*) [20] and black cumin (*Nigella sativa*) [6] led to stimulation of the immune system, improvement of growth performance and disease resistance in rainbow trout. *Coriandrum sativum* known by common names coriander and cilantro, is an annual herb of Apiaceae (or carrot) family. Coriander is native to South-Eastern Europe and grows extensively all over Europe, Middle East, China, India and Turkey [21,22]. Unlike other medicinal plants that grow only in certain areas, this plant is commercially cultivated worldwide and in different climates and its dry seed available throughout the year [23,24]. Coriander seeds contain a high value of vitamin- C (100 g of dry seeds provide 21 mg), some important fatty acids such as linoleic acid (omega 6), and minerals (Mg, Fe, Ca, Zn, and K) [24–27]. Also, Coriander seed contains 40–50% linalool, a terpenoid which is a powerful cellular antioxidant, antimicrobial, anti-inflammatory (Table 1). High availability and low production cost promise its application in aquaculture in large scale to provide better growth and protection at the same time. These findings suggest coriander seed as a great potential feed additive in aquaculture.

Several studies have been reported the beneficial effects of *C. sativum* against aflatoxicosis symptoms in Nile tilapia (*Oreochromis niloticus*) [26], Metronidazole in snakehead (*Channa punctatus*) [27], cadmium in rainbow trout (*Oncorhynchus mykiss*) [28] and *Aeromonas hydrophila* in catla (*Catla catla*) [29]. Up to date, there is no data available on the effect of dietary coriander seed extract (*Coriandrum sativum*) in rainbow trout. Thus, the present study was aimed to investigate the long-term effects of coriander seed extract on growth, immunity, and disease resistance against *Yersinia ruckeri* in rainbow trout.

2. Material and methods

2.1. Plant extraction process and diet preparation

Chemical composition of the extract isolated from the coriander seed analyzed by GC-MS (Gas chromatography-Mass Spectrometry, model- Shinadzu-9A), are shown in Table 1. GC-MS analysis was carried on a Varian Gas Chromatograph series 3400 fitted with a DB-5 ms fused silica capillary column (30 m × 0.25 mm, film thickness 0.25 μm).

In order to provide the plant extract, after air drying in shade, seeds

Table 2
Dietary formulation (g/kg) and proximate composition of the basal diet.

Ingredients	(g/kg)	Ingredients	(g/kg)
Fish meal	350	L-Carnithine	0.3
Corn gluten	175	salt	7.5
Wheat flour	180	Vitamin C	0.2
Soybean meal	130	Proximate composition of ingredients	%
Rice bran	36	Dry matter	91
Fish oil	23	Crude protein	40
Sunflower oil	48	Crude lipid	15
Vitamin premix	15	Ash	9
Mineral	15	Phosphorous	1.2
Molasses	20	Fiber	3

Vitamin contains amounts per kg of feed: retinol acetate (A), 10,000 IU; Cholecalciferol (D3), 6000 IU; DL-a-tocopheryl acetate (E), 600 mg; menadione sodium bisulfite (K3), 15 mg; L-ascorbic acid (C), 5400 mg; Biotin (H2), 2.4 mg; thiamin mononitrate (B1), 45 mg; riboflavin (B2), 75 mg; calcium D-pantothenate (B3), 7200 mg; niacin amide (B5), 135 mg; pyridoxine hydrochloride (B6), 45 mg; folic acid (B9), 24 mg; cyanocobalamin (B12), 120 mg; antioxidant 75 mg Mineral premix, amounts per kilogram of diet: mineral: Fe, 60 mg; Cu, 9 mg; Co, 0.7 mg; Se, 0.75 mg; Zn, 90 mg; Mn, 39 mg; I, 3 mg; cholinechloride, 150,000 mg.

(150 g weight) were grinded using electric grinder (Pars Khazar brand) then methanol (85%, 1.5 L amount) was added. To allow proper extraction, the mixture was left in ambient condition for 48 h and thoroughly shaken to prevent sedimentation [9]. Then mixture was filtered using Whatman no. 1 paper, the filtrate was concentrated using a rotary evaporator at around 50 °C. Finally, 20 ml sample of concentrated extract was obtained from 150 g plant seed powder samples. The extract was freeze dried using (brand Martin christ, D-37520 Osterode, Germany) and was kept in the fridge until use [7].

Experimental diets were provided using commercial feed (Faradaneh, Shahrekord, Iran, Table 2). The commercial diet lacked any plant extracts and other supplementation. To prepare the desired diet, the commercial pellet was milled and mixed with coriander seed extract at ratios of 0, 0.5%, 1% and 2% and then pellets were made by an industrial grinder and subsequently dried for 2 h in 40 °C [30]. Pellets were packed in nylon bags and kept in the fridge until use. Diets preparation and dosages were performed according to previous studies by Awad et al. [8] and Moghanlou et al. [30].

2.2. Fish husbandry

Six hundred rainbow trout (62 ± 0.81 g) were obtained from private rainbow trout fish farm, Urmia, Iran. After one week of quarantine, fish were allowed to adopt the experimental conditions for a week and then distributed into four dietary groups in 12 polyethylene tanks (300 L) at stocking density of fifty per each tank (one hundred fifty fish per treatment). Fish were fed three times a day (8:00, 13:00 and 19:00) with the previously mentioned diets for eight weeks based on the water temperature and fish biomass (1.5%). Fish were weighed every week to adjust feeding rate.

In order to maintenance water quality during the experimental period, uneaten food and feces were removed by siphoning and water physicochemical parameters were monitored daily as follows: Oxygen: 7–8 mg L⁻¹, temperature: 15 ± 2 °C and pH: 7–8.

2.3. Fish biometry

At the end of the experiment, all fish were taken out of each tank in order to measure growth factors using following equations:

$$\text{Condition factor (CF)} = (\text{wet body weight} \times 100) \div (\text{total length})^3$$

$$\text{Specific growth rate (SGR) (\%/day)} = [(\text{Ln Final weight} - \text{Ln initial weight}) \div \text{time}] \times 100.$$

$$\text{Feed conversion ratio (FCR)} = \text{Feed intake} \div \text{Weight gain}.$$

Table 3

Effects of dietary *Coriandrum sativum* extract administered over an eight weeks period on the growth performance and feed utilization of rainbow trout (*Oncorhynchus mykiss*).

Parameters	Control	CSE .05%	CSE 1%	CSE 2%
Initial weight (g)	62.33 ± 1.89 ^a	61.43 ± 0.60 ^a	63.40 ± 0.81 ^a	62.20 ± 1.57 ^a
Final weight [g]	90.45 ± 1.3 ^a	94.63 ± 0.83 ^b	93.88 ± 0.92 ^{ab}	96.33 ± 2.25 ^b
FI	52.33 ± 1.54 ^a	51.60 ± 0.5 ^a	53.24 ± 0.66 ^a	52.24 ± 1.31 ^a
FCR	1.88 ± 0.28 ^a	1.55 ± 0.08 ^a	1.74 ± 0.05 ^a	1.53 ± 0.02 ^a
SGR [%/Day]	0.62 ± 0.07 ^a	0.72 ± 0.03 ^{ab}	0.65 ± 0.01 ^{ab}	0.73 ± 0.01 ^b
CF	1.25 ± 0.03 ^b	1.17 ± 0.02 ^a	1.27 ± 0.08 ^{bc}	1.31 ± 0.02 ^c
SR [%]	91.33 ± 1.20 ^a	92.33 ± 0.88 ^{ab}	95.00 ± 0.57 ^{ab}	96.00 ± 0.57 ^b

Values in row assigned with different letter denote significant difference ($P < 0.05$). Data are presented as mean ± SD. FI; feed intake; FCR, food conversion ratio; SGR, specific growth rate CF, condition factor; SR; survival rate.

Survival (%) = [(final amount of fish) ÷ (initial amount of fish)] × 100.

2.4. Sample collection

At the end of feeding trials, fish were starved for 24 h before sampling. Five individual fish samples per tank were randomly selected and anaesthetized by clove powder (200 ppm). Blood samples were taken using 2 mm syringe from caudal vein. One part of the blood sample was transferred to a heparinized vial for the evaluation of hematology. Another part was placed into vials (without heparin) allowed to clot at room temperature for 1 h then kept at 4 °C for 4 h. All samples were separated by centrifugation, at 1600 g for 5 min and the supernatant was kept at –80 °C for subsequent analysis [31].

2.5. Hematological analyses

2.5.1. Hematocrit (%)

Hematocrit was measured using the technique as described by Brown [32] and reported as percentage packed cell volume (% PCV).

2.5.2. Hemoglobin

Optical Density full definition (OD) factor of solution was measured using semi-automatic spectrophotometry at 540 nm and compared to standard curve in order to determine hemoglobin (g/dl) based on cyano-haemoglobin method [33].

2.5.3. Measurement of leukocytes, RBC and MCV, MCH and MCHC parameters

Blood samples were diluted 200 times in red blood cell pipette with physiology serum and RBC was calculated in Neubauer hemocytometer and then multiplied in 10^5 constant values [30]. Diluted blood samples in ratio of 20 times with physiology serum in white blood cell pipette were used in hemocytometer and then calculated leukocytes in terms of volume unit multiplied in 50 constant value [34].

The average red blood cell volume (MCV), the mean red blood cell hemoglobin (MCH) and the mean blood concentration of hemoglobin in the red blood cells (MCHC) parameters through following equations [35]: $MCHC = Hb \times 10/Hct$ $MCV = Hct \times 10/RBC$ (million) $MCH = Hb \times 10/RBC$ (million).

2.6. Serum total protein, albumin and globulin

Total protein of serum and albumin and globulin were determined using spectrophotometer kits (Pars Azmoon Co, Tehran, Iran) and Colorimetric method [36].

2.7. Innate immune response

2.7.1. Immunoglobulin and lysozyme activity

Immunoglobulin was determined through ELISA and Nephstar kits

[36]. According to on Clerton et al. [37] lysozyme activity was measured in terms of susceptible characterized gram positive bacteria *Micrococcus luteus* (Sigma, M 3770, St. Louis, USA).

2.7.2. Alternative complement pathway activity

Alternative complement pathway activity (ACH50) was determined as the method described White and Fletcher [38]. The volume of supernatant complement producing 50% hemolysis was determined, and used to estimate the complement activity.

2.8. *Y. ruckeri* challenge

After eight weeks feeding trial, 30 fish from each dietary treatment (10 fish per each tank) were randomly selected, anaesthetized with clove powder (200 ppm) and then were challenged by I.P injection with 0.1 ml of a suspension of *Y. ruckeri* (BCCM5/LMG3279) (1×10^7 cells ml^{-1}). Dead fish were removed and examined microbiologically for up to 14 days. During this period mortality rate was recorded [31].

2.9. Statistical analysis

SPSS software version 21 was used for data analysis. One-way ANOVA was applied to analyze growth and immune parameters data and Tukey's test was used to compare means at significant $P < 0.05$. All data represented as mean ± SD.

3. Results

3.1. Fish biometry

Table 3 represents measured values of growth factors. Based on our results, 2% dietary incorporation of CSE showed significant difference in case of CF, SR, SGR and FW compared to group control ($P < 0.05$); while no significant difference was found among experimental groups in case of FCR and FI ($P > 0.05$). (Table 3).

3.2. Hematological parameters

Mean measured values of hematocrit, red and white blood cells and hemoglobin are represented in Table 4. Results showed that the most amount of hematocrit was related to 2% of CSE and significant difference was found when comparing to other treatments and control ($P < 0.05$). Also, the least amount of hematocrit was found in control treatment. Results from calculation of blood cells revealed that fish fed by 2% of CSE show increase in hemoglobin which is significantly different from control group ($P < 0.05$). No significant difference was found among dietary treatment and control in case of red and white blood cells ($P > 0.05$).

The highest amount of MCV, MCHC, and MCH was observed in 2% of CSE, However no significant difference was found between dietary treatments at the end of eight weeks-long period of experiment

Table 4

Hematological parameters of rainbow trout fed control diet and diet supplemented with different levels of coriander seed extract (CSE) after eight weeks.

	Control	CSE 0.5%	CSE 1%	CSE 2%
Hct [%]	39.83 ± 0.26 ^a	41.83 ± 1.04 ^{ab}	41.6 ± 2.6 ^a	45.93 ± 1.44 ^b
RBC [$10^6 \times \text{cell ml}^{-1}$]	1.31 ± 0.52 ^a	1.28 ± 0.81 ^a	1.32 ± 0.04 ^a	1.39 ± 0.04 ^a
WBC [$10^3 \times \text{cell ml}^{-1}$]	5.03 ± 0.98 ^a	4.77 ± 1.44 ^a	4.8 ± 0.65 ^a	5.53 ± 0.51 ^a
Hb [g dl ⁻¹]	10.36 ± 0.81 ^a	11.36 ± 1.7 ^{ab}	12.4 ± 2.92 ^{ab}	15.1 ± 0.62 ^b
MCV [nm ³]	304.11 ± 11.15 ^a	327.42 ± 14.82 ^a	313.34 ± 10.92 ^a	329.66 ± 7.23 ^a
MCHC [g dl ⁻¹]	2.6 ± 0.19 ^a	2.71 ± 0.34 ^a	2.96 ± 0.55 ^a	3.29 ± 0.22 ^a
MCH [$\mu\text{g cell}^{-1}$]	79.25 ± 7.5 ^a	88.47 ± 7.81 ^a	93.16 ± 8.04 ^a	108.48 ± 6.61 ^a

Values in row assigned with different letter denote significant difference ($P < 0.05$). Data are presented as mean ± SD.

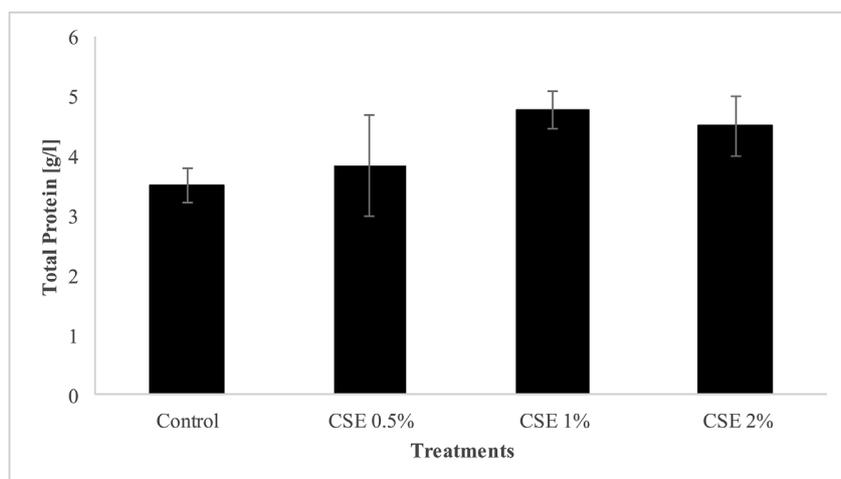


Fig. 1. Serum total protein of rainbow trout fed different levels of coriander seed extract (CSE) for eight weeks. Data are expressed as the mean ± SD. Bars without letters are not significantly different ($P > 0.05$).

(Table 4).

3.3. Total protein, albumin and globulin of serum

Blood parameters of rainbow trout fed different levels of coriander extract are presented in Figs. 1–3. The highest amount of total protein was recorded in 1% of CSE although no significant difference was found between coriander dietary treatments and control ($P < 0.05$) (Fig. 1). Determination of serum albumin and globulin revealed no significant difference between dietary treatments and control ($P < 0.05$) (Figs. 2, 3).

3.4. Innate immune response

Lysozyme and complement activity were measured in 2% of CSE treatment as the highest values and significant difference was found compared to control group ($P < 0.05$) (Figs. 4, 5). Immunoglobulin assessment showed no significant difference between dietary treatments at different levels of CSE compared to control ($P < 0.05$). However, the highest amount was associated with 2% CSE treatment (Fig. 6).

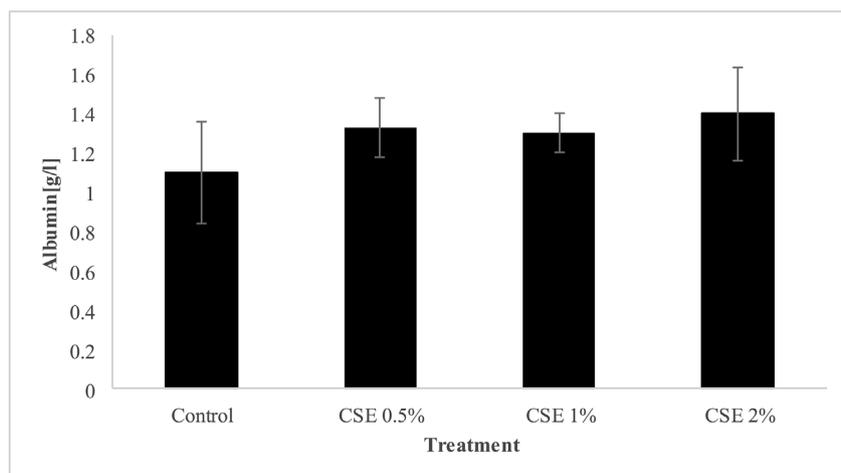


Fig. 2. Serum albumin of rainbow trout fed different levels of coriander seed extract (CSE) for eight weeks. Data are expressed as the mean ± SD. Bars without letters are not significantly different ($P > 0.05$).

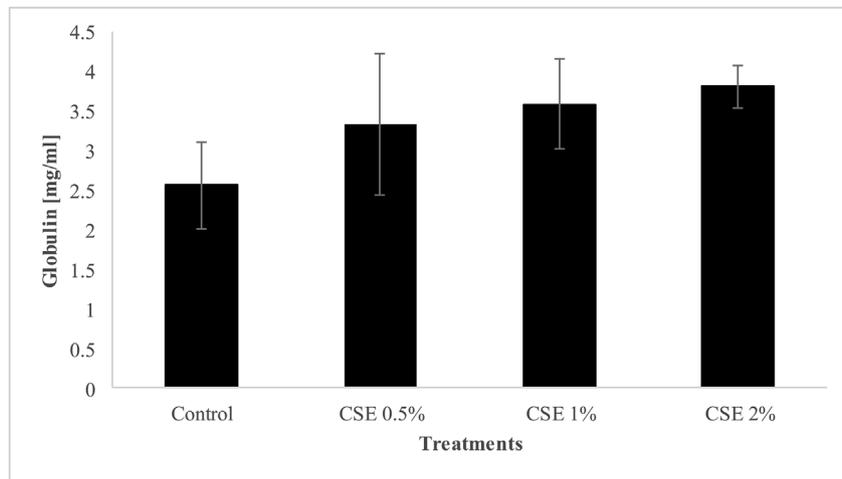


Fig. 3. Serum globulin of rainbow trout fed different levels of coriander seed extract (CSE) for eight weeks. Data are expressed as the mean \pm SD. Bars without letters are not significantly different ($P > 0.05$).

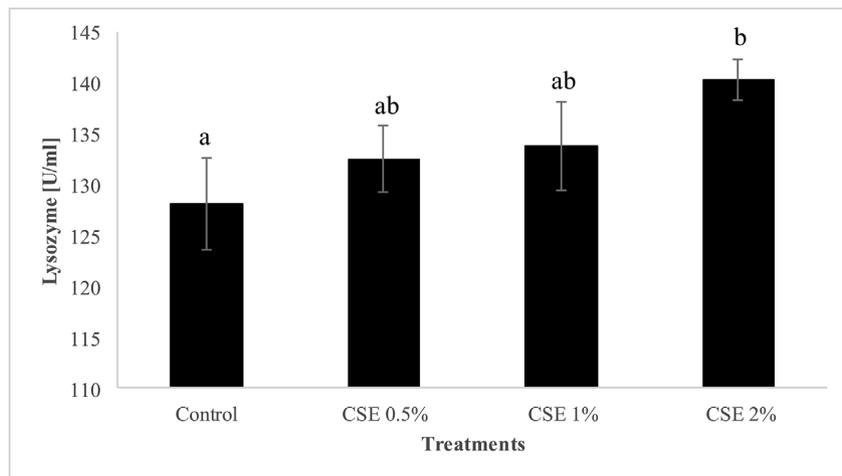


Fig. 4. Serum lysozyme rainbow trout fed different levels of coriander seed extract (CSE) for eight weeks. Data are expressed as the mean \pm SD. Bars with different letters are significantly different ($P < 0.05$).

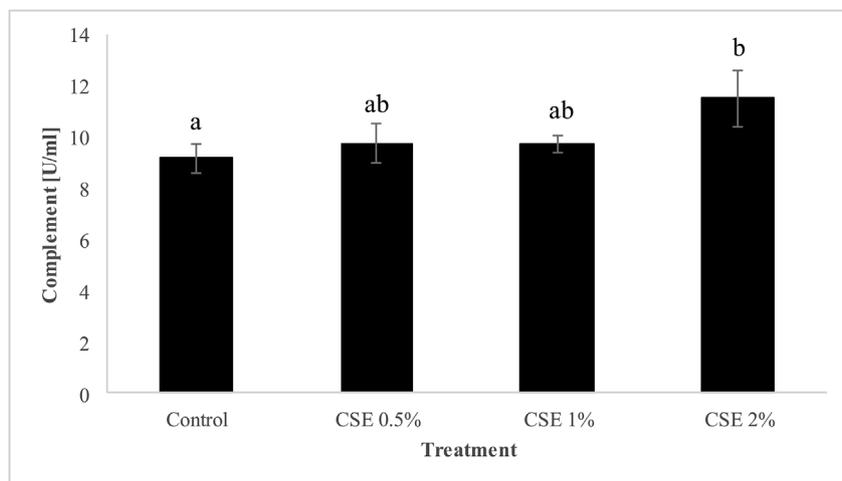


Fig. 5. Serum complement of rainbow trout fed different levels of coriander seed extract (CSE) for eight weeks. Data are expressed as the mean \pm SD. Bars with different letters are significantly different ($P < 0.05$).

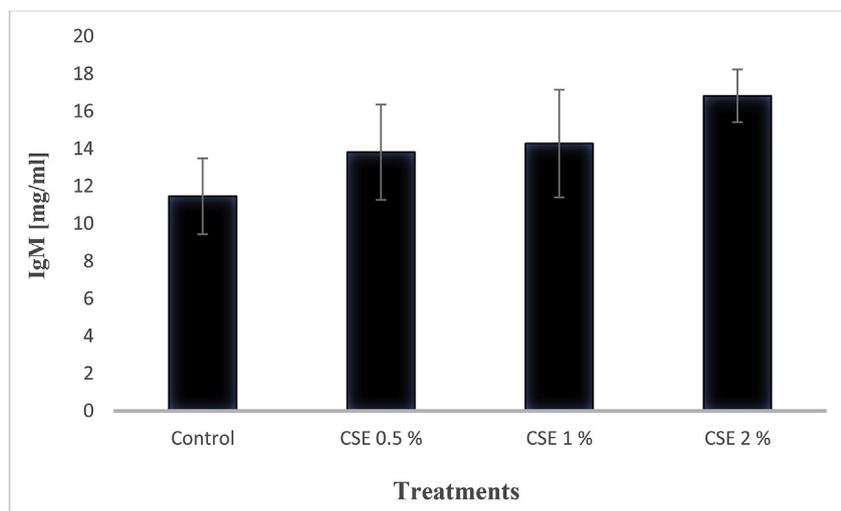


Fig. 6. Serum total immunoglobulin (IgM) of rainbow trout fed different levels of coriander seed extract (CSE) for eight weeks. Data are expressed as the mean \pm SD. Bars without letters are not significantly different ($P > 0.05$).

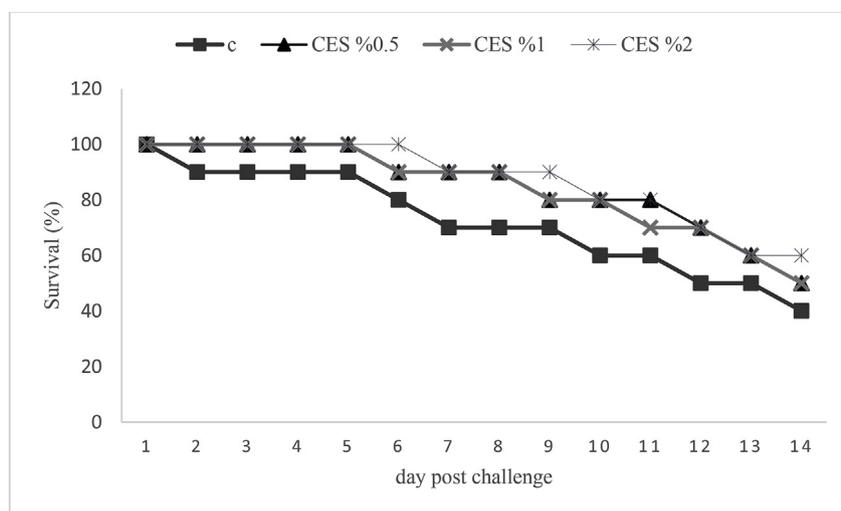


Fig. 7. Survival (%) of rainbow trout, *O. mykiss* fingerlings fed different levels of dietary 0, 0.5%, 1% and 2% of for 14 days post challenge with *Y. rukerri*.

3.5. Challenge test

Our results indicated that the use of CSE in diet for rainbow trout lowered the level of mortality in treatment groups compared to control group. 2% CSE treatment exhibited the lowest mortality rate when challenging fish with *Y. rukerri* up to 40% at the day 14th while 60% mortality was observed in control group (Fig. 7). However, no significant differences were observed in fish fed the control diet or treated diet ($P > 0.05$).

4. Discussion

The present study indicates that supplementation of coriander seed extract in rainbow trout diets optimizes growth performance (condition factor, specific growth rate and final weight) in eight weeks. This might be related to several factors including the protection of nutrients in intestine due to bactericidal effects of CSE on the bacterial pathogens of the intestine, increased levels of digestive enzymes, and better cellular respiration and nutrient uptake resulting in an increase in the number of red blood cells [8,9,24,27]. Similarly, many studies have been reported the potential effect of plant extracts on growth performance. For example, supplementation of diet with ginseng (*Panax notoginseng*) in Nile tilapia (*O. niloticus*) [39], astragalus (*Astragalus membranaceus*) in

Nile tilapia (*O. niloticus*) [40], Aloe vera (*Aloe barbadensis*) in rainbow trout (*O. mykiss*) [41], mongolian onion (*Allium mongolicum*) in Snakeheads juvenile (*Channa argus*) [42], moringa (*Allium mongolicum*) in giant freshwater prawn (*Macrobrachium rosenbergii*) [43], rosemary (*Rosmarinus officinalis*) in common carp (*Cyprinus carpio*) [44], velvet bean (*Mucuna pruriens*) in Mozambique tilapia (*O. mossambicus*) [45], black plum (*Syzygium cumini*) leaf powder in whiteleg shrimp (*Litopenaeus vannamei*) [46].

Hematological parameters are useful tools for monitoring fish health status and nutritional metabolism in response to the dietary supplementation [47–52]. In the present study, the highest level of WBC, RBC, MCV, MCH, MCHC were observed in fish fed with 2% dosage of CSE, and the amount of hematocrit and hemoglobin in the treatment significantly increased in compared to control group. Similar results were recorded from feeding rainbow trout with lamb's ears (*Stachys lavandulifolia*) [30], peppermint (*Mentha piperita*) [53], silymarin (*Silybum maritimum*) [54] stinging nettle (*Urtica dioica*) [55]. It has been reported that increased number of blood cells might be related to the effects of plant extracts on lymphoid organs [48].

Albumin and globulin are included as total serum protein which possesses a wide spectrum of biological functions in fish (e.g. albumin play an important role in transferring different compounds such as drugs) [54]. Therefore, stimulation of synthesizing these proteins by

liver or other sectors of the immune system led to increased immune responses [54]. The amounts of these factors are considered as health status indicators and often they strongly affect the immune system [56].

The results showed that supplementation of diet with CSE had no significant effects on levels of total protein, globulin and albumin. In contrast, the positive effects of several plant extracts such as peppermint (*M. piperita*) [57], Wood betony (*S. lavandulifolia*) [30], aloe vera (*A. barbadensis*) [41], green tea (*Camellia sinensis*) [58], and silymarin (*S. Marinum*) [54] are recorded in biochemical improvement of rainbow trout.

The stimulation or enhancement of the immune system depends on the activation of the defensive elements of the body by different factors (vaccine, nutrition, infections, environmental condition) [47–49]. The gut is one of the most important immune organs that is constantly exposed to various antigens. Improving the performance of this organ plays an important role in growth performance and host immune responses. The CSE can modulate the intestinal microflora through the destruction of the cell wall of harmful bacteria. On the other hand, the plant extract contains several phenolic compounds that can stimulate the immune system by the production of bioactive molecules (immunoglobulin, lysozyme, complement) and increasing the activity of phagocytosis [29,50,59].

In the present study, fish fed with the 2% of CSE had the highest IgM level and the activity of lysozyme and alternative complement. In addition, dietary supplementation of 2% of CSE significantly increased, alternative complement and serum lysozyme activity of rainbow trout. Furthermore, using different medical plants, such as peppermint (*M. piperita*) in caspian white fish (*Rutilus frisii kutum*) [57], caterpillar fungus (*Cordyceps militaris*) in Nile tilapia (*O. niloticus*) [60], hawthorn (*Crataegus monogyna*) extract in golden pompano (*Trachinotus ovatus*) [61], fenugreek seeds (*Trigonella foenum-graecum*) in gilthead seabream, (*Sparus aurata*) [14], and dandelion (*Taraxacum officinale*) extract in golden pompano (*T. ovatus*) [56] showed significantly increased in lysozyme and complement activities. Although action behind immunomodulatory nature of coriander remained to be clarified, it might be attributed to the presence of coriander extract. The high ACH50 and lysozyme activity might be related to the improvement of liver performance and WBC count because the main source of ACH50 and lysozyme are liver and WBC, respectively [47].

Linalool and Geranyl acetate as the major components of CSE, which are known to possess a wide spectrum of biological activities such as anti-oxidant, anti-microbial, analgesic and anti-inflammatory effects [25,26]. More recently, reported that CSE contains a novel water-soluble component with an immunostimulatory effect on macrophages. The CSE would contribute to activating host defense mechanism against pathogens by stimulating innate immunity [27,28].

Challenge test using bacteria has recently been considered as a powerful tool for evaluating the effects of supplemented diets in regards of pathogens' inhibition and fish health status indicator post-feeding [60,62]. *Y. ruckeri* is known as a causative infectious agent of enteric red-mouth disease which causes mass mortalities and considerable economic losses particularly in rainbow trout and Atlantic salmon fish farms [63].

Dietary administration of the *C. sativum* has been shown to protect the animals against bacteria [26,27], fungi and parasite [28]. In recent years, dietary application of herbal extracts can increase resistance of fish to a wide range of pathogenic bacteria, such as milky mangrove (*Excoecaria agallocha*) leaf extracts against *Streptococcus agalactiae* [64], stinging nettle (*U. dioica*) against *S. iniae*, *Y. ruckeri*, *Vibrio anguillarum* and *Lactococcus garviae* [55], dandelion (*T. officinale*) and hawthorn (*C. Monogyna*) extracts against *Vibrio harveyi* [56,61], and velvet bean (*M. Pruriens*) seed meal against *A. hydrophila* [45].

In the present study, dietary CSE showed increased survival rate of rainbow trout against *Y. ruckeri*. However, no remarkable differences were observed between control and treated groups ($P > 0.05$). It has been reported that plant essential oil-rich terpenes, such as thymol,

limonene, carvacrol, cinnamaldehyde and eugenol were able to enter the membrane lipid bilayer, disrupt lipid packing and change membrane fluidity [65]. These activities lead to an alteration in cell permeability and cell death [66]. Therefore, the destruction of the cellular membrane was supposed to be a possible primary mode of anti-microbial and antifungal actions of the coriander seed extract [63].

In conclusion, CSE can improve growth performance and some immunological indices of rainbow trout. Dietary levels of 2% CSE is recommended for rainbow trout in order to enhance fish health and resistance against *Y. ruckeri* infection.

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Conflicts of interest

There is no conflict of interest to declare.

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